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Machine Shop, Armour Institute of Technology

CYCLOPEDIA

OF

Modern Shop Practice

A Manual of

SHOP PRACTICE, PATTERN MAKING, MACHINE DESIGN,
FOUNDRY AND MACHINE SHOP WORK, FORGING,
TOOL MAKING, SHEET METAL WORK, STEAM,
REFRIGERATION, ELECTRICITY, ETC.

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DEAN, ARMOUR INSTITUTE OF TECHNOLOGY.

Assisted by a Corps of

SHOP EXPERTS, DESIGNERS AND ENGINEERS

Illustrated with over Two Thousand Engravings

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1904

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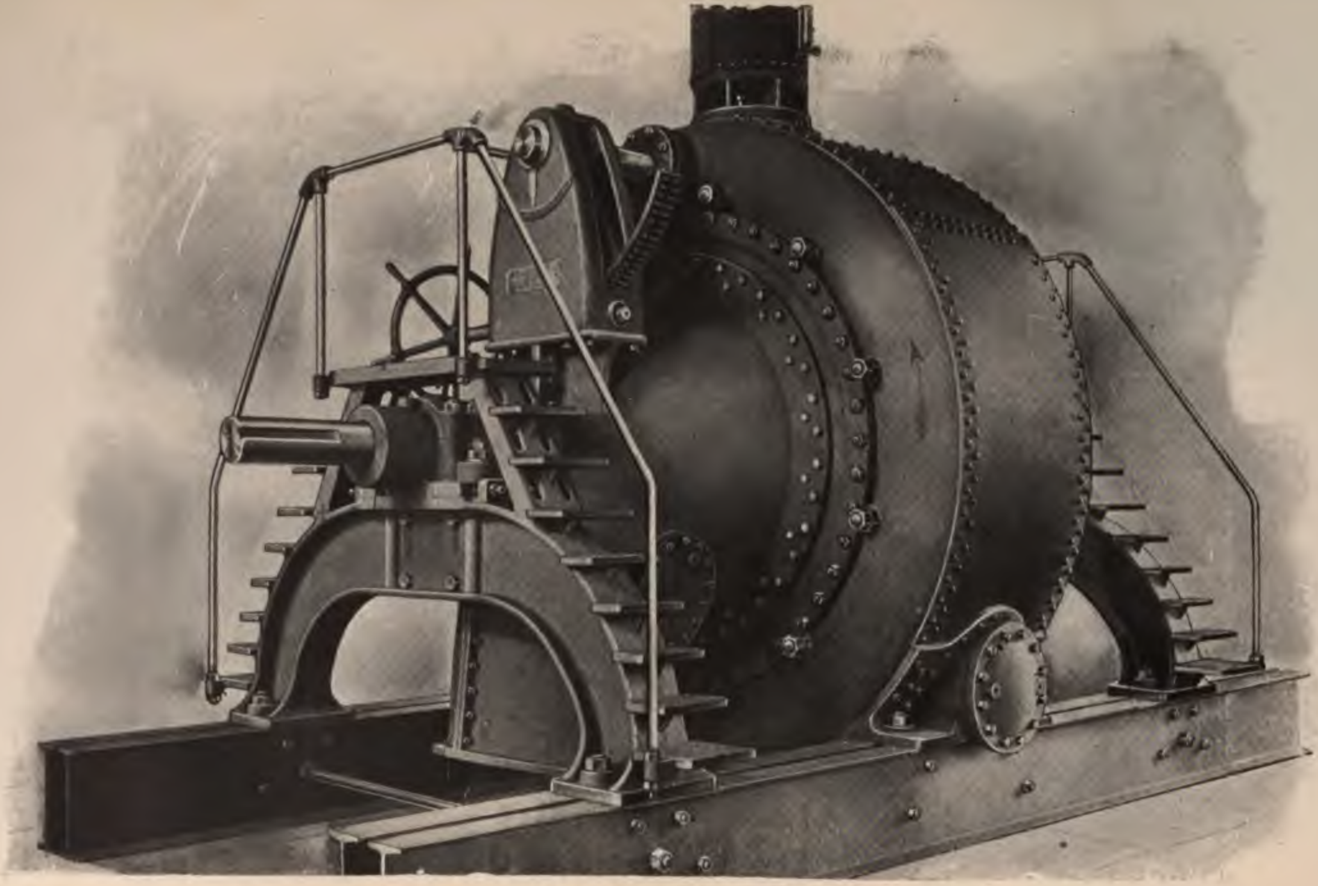
Introductory Note.

THE successful education of the man in the shop is a question of vital importance. The difficulties under which he toils in his struggle for advancement, and his daily labor, render impossible the usual means of education, and prevent the attending of a resident technical school. Probably the most successful substitute for such a school is the correspondence method of instruction. Thousands of mechanics are improving their conditions by devoting a half hour each day in systematic study under the direction of men who have had long experience in teaching, and in practical shop work. There are, however, many who cannot afford the time and expense necessary for even a correspondence school course. For such the Cyclopedia of Modern Shop Practice is prepared.

¶ This Cyclopedia is compiled from the most practical and most valuable Instruction Papers of the American School of Correspondence. These Instruction Papers have been prepared especially for home study and are intended primarily for such work. As their extended use in the American School of Correspondence has proved them to be of great practical value, and a successful means of instruction, they form a reliable treatise on the subject of shop practice.

¶ The correspondence student needs a thoroughly technical work free from superfluous theory; in like manner the reader of the Cyclopedia must have the necessary theories carefully explained, and the results of practical experience clearly pointed out. By giving the best material on shop practice to the busy man in the shop, the editors hope that he will achieve the success that results from a combined knowledge of theory and practice.



HIGH DUTY SAMPSON TURBINE. NIAGARA DESIGN.
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MACHINE DESIGN.

PART I.

Definition. Machine Design is the art of mechanical thought, development, and specification.

It is an art, in that its routine processes can be analyzed and systematically applied. Proficiency in the art positively cannot be attained by any "short cut" method. There is nothing of a spectacular nature in the methods of Machine Design. Large results cannot be accomplished at a single bound, and success is possible only by a patient, step-by-step advance in accordance with well-established principles.

"Mechanical thought" means the thinking of things strictly from their mechanical side; a study of their mechanical theory, structure, production, and use; a consideration of their mechanical fitness as parts of a machine.

"Mechanical development" signifies the taking of an idea in the rough, in the crude form, for example, in which it comes from the inventor, working it out in detail, and refining and fixing it in shape by the designing process. Ideas in this way may become commercially practicable designs.

"Mechanical specification" implies the detailed description of designs, in such exact form that the shop workmen are enabled to construct completely and put in operation the machines represented in the designs.

The object of Machine Design is the creation of machinery for specific purposes. Every department of a manufacturing plant is a controlling factor in the design and production of the machines built there. A successful design cannot be out of harmony with the organized methods of production. Hence in the high development of the art of Machine Design is involved a knowledge of the operations in all the departments of a manufacturing plant. The student is therefore urged not only to familiarize himself with the direct production of machinery, but to study the relation thereto of the allied commercial departments.

He should get into the spirit of business at the start, get into the shop atmosphere, execute his work just as though the resulting design were to be built and sold in competition. He should visit shops, work in them if possible, and observe details of design and methods of finishing machine parts. In this way he will begin to store up bits of information, practical and commercial, which will have valuable bearing on his engineering study.

The labor involved in the design of a complicated automatic machine is evidenced by the designer's wonderful familiarity with its every detail as he stands before the completed machine in operation and explains its movements to an observer. The intricate mass of levers, shafts, pulleys, gears, cams, clutches, etc., etc., packed into a small space, and confusing even to a mechanical mind, seems like a printed book to the designer of them.

This is so because it is a familiar journey for the designer's mind to run over a path which it has already traversed so many times that he can see every inch of it with his eyes shut. Every detail of that machine has been picked from a score or more of possible ideas. One by one, ideas have been worked out, laid aside, and others taken up. Little by little, the special fitness of certain devices has become established, but only by patient, careful consideration of others, which at first seemed equally good.

Every line, and corner, and surface of each piece, however small that piece may be, has been through the refining process of theoretical, practical, and commercial design. Every piece has been followed in the mind's eye of its designer from the crude material of which it is made, through the various processes of finishing, to its final location in the completed machine; thus its bodily existence there is but the realization of an old and familiar picture.

What wonder that the machine seems simple to the designer of it! As he looks back to the multitude of ideas invented, worked out, considered and discarded, the machine in its final form is but a trifle. It merely represents a survival of the fittest.

No successful machine, however simple, was ever designed that did not go through this slow process of evolution. No machine ever just simply happened by accident to do the work for which it is valued. No other principle upon which the successful design of machinery depends is so important as this careful, patient consideration of detail. A machine is seldom unsuccessful because some main point of construction is wrong. The principal features of a machine are usually the easiest to determine. It is a failure because some little detail was overlooked, or hastily considered, or allowed to be neglected, because of the irksome labor necessary to work it out properly.

There is no task so tedious, for example, as the devising of the method of lubricating the parts of a complicated machine. Yet there is no point of design so vital to its life and operation as an absolute assurance of an adequate supply of oil for the moving parts at all times and under all circumstances. Suitable means often cannot be found, after the parts are together, hence the machine goes into service on a risky basis, with the result, perhaps, of early failure, due to "running dry." Good designers will not permit a design to leave their hands which does not provide practically automatic oiling, or at least such means of lubrication that the operator can offer no excuse for neglecting to oil his machine. This is but a single illustration of many which might be presented to impress the definite and detail character necessary in work in Machine Design.

Relation. The relation which Machine Design should correctly bear to the problems that it seeks to solve, is twofold; and there are, likewise, two points of view corresponding to this twofold relation, from which a study of the subject should be traced. Neither of these can be discarded and an efficient mastery of the art attained. These points are—

I. Theory.
II. Production.

I. *Theory.* From this point of view, Machine Design is merely a skeleton or framework process, resulting in a representation of ideas of pure motion, fundamental shape, and ideal proportion. It implies a working knowledge of physical and mathematical laws. It is a strictly scientific solution of the problem at hand, and may be based purely on theory which has been reasoned out by calculation or deduced from experiment. This is the only sure foundation for intelligent design of any sort.

But it is not enough to view the subject from the standpoint of theory alone. If we stopped here we should have nothing but mechanisms, mere laboratory machines, simply structures of ingenuity and examples of fine mechanical skill. A machine may be correct in the theory of its motions; it may be correct in the theoretical proportions of its parts; it may even be correct in its operation for the time being; and yet its complication, its misdirected and wasteful effort, its lack of adjustment, its expensive and irregular construction, its lack of compactness, its difficulty of ready repair, its inability to hold its own in competition—any of these may throw the balance to the side of failure. Such a machine, commercially considered, is of little value. No shop will build it, no machinery house will sell it, nobody will buy it if it is put on the market.

Thus we see that, aside from the theoretical correctness of principle, the design of a machine must satisfy certain other exacting requirements of a distinctly business nature.

II. *Production*. From this point of view, Machine Design is the practical, marketable development of mechanical ideas. Viewed thus, the theoretical, skeleton design must be so clothed and shaped that its production may be cheap, involving simple and efficient processes of manufacture. It must be judged by the latest shop methods for exact and maximum output. It must possess all the good points of its competitor, and, withal, some novel and valuable ones of its own. In these days of keen competition it is only by carefully studied, well-directed effort toward rapid, efficient, and, therefore, cheap production that any machine can be brought to a commercial basis, no matter what its other merits may be. All this must be thought of and planned for in the design, and the final shapes arrived at are quite as much a result of this second point of view as of the first.

As a good illustration of this, may be cited the effect of the present somewhat remarkable development of the so-called "high speed" steels. The speeds and feeds possible with tools made of these steels are such that the driving power, gearing, and feed mechanism of the ordinary lathe are wholly inadequate to the demands made upon them when working the tool to its limit. This r[illegible] basis of design as used for the ordinary tool [illegible] is expected to stand up to the cuts possible with the new steels. Hence, while the old designs were right for the old standard, a new one has been set, and a thorough revision on a high-speed basis is imminent, else the market for them as machines of maximum output will be lost.

From these definitions it is evident that the designer must not only use all the theory at his command, but must continually inform himself on all processes and conditions of manufacture, and keep an eye on the tendency of the sales markets, both of raw material and the finished machinery product. This is what in the broadest sense is meant by the term "Mechanical Thought," thought which is directed and controlled, not only by theoretical principle but by closely observed practice. From the feeblest pretenders of design to those engineers who consummate the boldest feats and control the largest enterprises, the process which produces results is always the same. Although experience is necessary for the best mechanical judgment, yet the student must at least begin to cultivate good mechanical sense very early in his study of design.

Invention. Invention is closely related to Machine Design, but is not design itself. Whatever is invented has yet to be designed. An invention is of little value until it has been refined by the process of design.

Original design is of an inventive nature, but is not strictly invention. Invention is usually considered as the result of genius, and is announced in a flash of brilliancy. We see only the flash, but behind the flash is a long course of the most concentrated brain effort. Inventions are not spontaneous, are not thrown off like sparks from the blacksmith's anvil, but are the result of hard and applied thinking. This is worth noting carefully, for the same effort which produces original design may develop a valuable invention. But there is little possibility of inventing anything except through exhaustive analysis and a clear interpretation of such analysis.

Handbooks and Empirical Data. The subject matter in these is often contradictory in its nature, but valuable nevertheless. Empirical data are data for certain fixed conditions and are not general. Hence, when handbook data are applied to some specific case of design, while the information should be used in the freest manner, yet it must not be forgotten that the case at hand is probably different, in some degree, from that upon which the data were based, and unlike any other case which ever existed or will ever again exist. Therefore the data should be applied with the greatest discretion, and when so applied will contribute to the success of the design at least as a check, if not as a positive factor.

The student should at the outset purchase one good handbook, and acquire the habit of consulting it on all occasions, checking and comparing his own calculations and designs therefrom. Care must be taken not to become tied to a handbook to such an extent that one's own results are wholly subordinated to it. Independence in design must be cultivated, and the student should not sacrifice his calculated results until they can be shown to be false or based on false assumption. Originality and confidence in design will be the result if this course be honestly pursued.

Calculations, Notes, and Records. Accurate calculations are the basis of correct proportions of machine parts. There is a right way to make calculations and a wrong way, and the student will usually take the wrong way unless he is cautioned at the start.

The wrong way of making calculations is the loose and shiftless fashion of scratching upon a scrap of detached paper marks and figures, arranged in haphazard form, and disconnected and incomplete. These calculations are in a few moments' time totally meaningless, even to the author of them himself, and are so easily lost or mislaid that when wanted they usually cannot be found.

Engineering calculations should always be made systematically, neatly, and in perfectly legible form, in some permanently bound blank book, so that reference may always be had to them at any future time for the purpose of checking or reviewing. Put all the data down. Do not leave in doubt the exact conditions under which the calculations were made. Note the date of calculation.

If a mistake in figures is made, or a change is found necessary, never rub out the figures or tear out the leaf, or in any way obliterate the figures. Simply draw a bold cross through the wrong part and begin again. Often a calculation which is supposed to be wrong is later shown to be right, or the facts which caused error may be needed for investigation is spent in making figures is always valuable time, time too precious to be thrown away by destroying the record.

The recording of calculations in a permanent form, as just described, is the general practice in all modern engineering offices. This plan has been established purely as a business policy. In case of error it locates responsibility and settles dispute. Consistent designing is made possible through the records of past designs. Proposals, estimates, and bids may often be made instantly, on the basis of what these record books show of sizes and weights. This bookkeeping of calculations is as important a factor of systematic engineering as bookkeeping of business accounts is of financial success.

The student should procure for this purpose a good blank book with a firm binding, size of page not smaller than 6 by 8 inches (perhaps 8 by 11 inches may be better), and every calculation, however small and apparently unimportant, should be made in it.

Sample pages of engineering calculations are reproduced in Figs. 3 to 9. Note the sketch showing the forces. Note the clear statement of data. Note the systematic writing of the equations, and the definite substitutions therein. Noto the heavy double underscoring of the result, when obtained. There is nothing in the whole process of the calculation that cannot be reviewed at any moment by anybody, and in the briefest time.

The development of a personal note-book is of great value to the designer of machinery. The facts of observation and experience recorded in proper form, bearing the imprint of intimate personal contact with the points recorded, cannot be equalled in value by those of any hand or reference book made by another. There is always a flavor about a personal note-book, a sort of guarantee, which makes the use of it by its author definite and sure.

The habit of taking and recording notes, or even knowing what notes to take, is an art in itself, and the student should begin early to make his note-book. Aside from the value of the notes themselves as a part of his personal equipment, the facility with which his eye will be trained to see and record mechanical things will be of great value in all of his study and work. How many men go through a shop and really see nothing of the operations going on therein, or, seeing them, remember nothing! An engineer, trained in this respect, will to a surprising degree be able to retain and sketch little details which fall under his eye for a brief moment only, while he is passing through a crowded shop.

Some draftsmen have the habit of copying all the standard tables of the various offices in which they work. While these are of some value in a few cases, yet this is not what is meant by a good note-book in the best sense. Ideas make a good note-book, not a mere tabulation of figures. If the basis upon which standards are founded can be transferred to permanent personal record, or novel methods of calculation, or simple features of construction, or data of mechanical tests, or efficient arrangement of machinery—if *these* can be preserved for reference, the note-book will be of greatest value.

Whatever is noted down, make clear and intelligible, illustrating by a sketch if possible. Make the note so clear that reference to it after a long space of years would bring the whole subject before the mind in an instant. If this is not done the author of the note himself will not have patience to dig out the meaning when it is needed; and the note will be of no value.

METHOD OF DESIGN.

The fundamental lines of thought and action which every designer follows in the solution of any problem in any class of work whatsoever, are four in number. The expert may carry all these in mind at the same time, without definite separation into a a step-by-step process; but the student must master them in their proper sequence, and thoroughly understand their application. In these four are concentrated the entire art of Machine Design. When they have become so familiar as to be instinctively applied on any and all occasions, good design is the result. The only other quality which will facilitate still further the design of good machinery is experience; and that cannot be taught, it must be acquired by actual work.

1. Analysis of Conditions and Forces. First, take a good square look at the problem to be solved. Study it from all sides, view it in all lights, note the worst conditions which can possibly exist, note the average conditions of service, note any special or irregular service likely to be called for.

With these conditions well in mind, make a careful analysis of all the forces, maximum as well as average, which may be brought into play. Make a rough sketch of the piece under consideration, and put in these forces. Be sure that these forces are at least approximately right. Go over the analysis carefully again and again. Remember that time saved at the beginning by hasty and poor analysis will actually be time lost at the end; and if the machine actually fails from this reason, heavy financial loss in material and labor will occur. Any haste toward completion of the structure beyond the roughest outline, without this careful study of forces, is a blind leap in the dark, entirely unscientific, and almost certain to result in ultimate failure.

On the other hand this principle may be carried too far. In trying to make the analysis thorough and the forces accurate, it is quite possible to consume more than a reasonable amount of time. Again, it is not always easy, and frequently impossible, to determine exactly the forces acting on a given piece. But their *nature*, whether sudden or slowly applied, rapid in action or only occurring at intervals, and their *approximate* direction and magnitude at least, are always capable of analysis. There are few, if any, cases where close assumptions cannot be made on the above basis and the design proceeded with accordingly. Hence the danger of too great refinement of analysis is simply to be avoided by the designer's plain business sense.

The first tendency of the student is to pass over the study of the forces as dull and dry, and attempt the design at once. He soon finds himself facing problems of which he sees no possible solution, and he bases his design on pure guess-work. This is the only solution possible from such a point of view, and is really no solution at all. A guess which has some rational backing is often successful; but in that case some analysis is required, and it is not a pure guess, but falls under the very principle we are considering.

There is no short cut to the design of machine parts which avoids this full understanding of the forces that they must sustain. The size of a belt depends upon the maximum pull upon it, and the designing of belts is nothing but providing sufficient cross-section of leather to prevent the belt tearing under the pull. Again, if pulley arms are not to break, or shafts twist off, or bolts be torn apart, or the teeth of gears fail, or keys and pins shear off, we must first, of course, find out what forces exist which are likely to produce stress that may lead to such breakage. We should not guess at the sizes, and then run the machine to see if breakage results, and then guess again. Machines are sometimes built in this way, but it is an unreasonable and uncertain method. We must use every effort to foresee the stress which a piece is liable to receive, before we decide its size. We must know all the forces approximately, if not positively. The analysis must be thorough enough to permit of reasonable assumption, if not positive assertion. It is manifestly impossible to solve any problem until we know exactly what the problem is; and a full analysis *is* the statement of the problem.

2. Theoretical Design. After we know by careful analysis what stress the machine part has to sustain, the next step is so to design it that it will theoretically resist the applied forces with the least expenditure of material.

We often see machinery with the metal of which it is made distributed in the worst possible manner. In places where the stress is heavy and a rigid member is needed, we find a weak, springy part; while in other parts, where there are no forces to be resisted, or vibration to be absorbed, there seems to be a waste of good material. Whether in such case the analysis of the forces was poor, or perhaps not made at all, or whether a knowledge of how to design so as to resist the given forces was wholly absent, cannot be told. At any rate, lack of either or both is clearly shown in the result.

Any member of a machine may vary in form from a solid block or chunk of material to an open ribbed structure. The solid chunk fills the requirement as far as strength is concerned, unless it is so heavy as to fail from its own weight. But such construction is poor design, except in cases where the concentration of heavy mass is necessary to absorb repeated blows like those of a hammer. The possibility of these blows [illegible] however, hav
been determined in the analysis; and [illegible]
then becomes theoretical design fo

For steadily applied load

structure can be made which will distribute the metal where it is theoretically needed, and each fiber will then sustain its proper share of the load. In this way weight, cost, and appearance are heeded; and the service of the piece is as good as, and probably better than, it would be with the clumsy, solid form.

There is no such thing as putting too much theory into the design of machinery. The strongest trait which an engineer can have is absolute faith in his analysis and calculations, and their reproduction in his theoretical design. Theoretical design is an indication of scientific advance in the art, and some of the greatest steps of progress which have been made in recent years have been accomplished through a purely theoretical study of machine structure.

It will never do, however, to be satisfied with theoretical design when it is not in accord with modern commercial and manufacturing considerations. Hence the next step after the determination of the theoretical design is the study of it from the producing standpoint.

3. Practical Modification. All theoretical design viewed from the business standpoint is worthless, unless it has been subjected to the test of cheap and efficient production. Each machine detail, though correct in theory, may yet be improperly shaped and unfit for the part it is to play in the general scheme of manufacture.

The conditions here involved are changeable. What is good design in this decade may be bad in the next. In this light the designer must be a close student of the signs of the times; he must follow the march of progress, closely applying existing resources, conditions, and facilities, otherwise he cannot produce up-to-date designs. The introduction of new raw materials, the cheapening of production of others, the changing of shop methods, the use of special machinery, the opening of new markets, the development of new motive agents, — all these and many others are constantly demanding some modification in design to meet competition.

Illustrative of this, note the change which has been wrought by the development of electric power, the rise and decline of the bicycle business, the present manufacture of automobiles, the last named especially with reference to the development of the small motive unit, the gasolene engine, the steam engine, etc. The design of much machinery has been materially changed to meet the exacting demands of these new enterprises.

Practical modifications of design necessary to meet the limitations of construction in the pattern shop, foundry, and machine shop are of daily application in the designer's work. He must keep in his mind's eye at all times the workmen and the processes they use to create his designs in metal in the shop.

"How can this be made?" "Can it be made at all?" "Can it be made cheaply?" "Will it be simple in operation after it is made?" "Can it be readily removed for repair?" "Can it be lubricated?" "How can it be put in place?" "How can it be gotten out?" "Will it be made in small quantities or large?" "Will it sell as a special or standard machine?" etc., etc.

The consideration of such questions as these is a practical necessity as a business matter. No other feature affects the design of machinery more, perhaps; for designs which cannot be built as business propositions are no designs at all.

The student, it is true, may not have the extended shop knowledge which is essential to this; but he can do much for himself by visiting shops whenever possible, getting hold of shop ways of doing things, and invariably treating his work as a business matter. Though a man may not be a pattern maker, molder, blacksmith, or machinist, yet he can soon gain ideas of the processes in each of these branches which will be of immense advantage to him in his designing work.

4. **Delineation and Specification.** This means the clear and concise representation of the design by mechanical drawings.

This is as much a part of the routine method of Machine Design as the other three points which have been discussed. The mere act of putting the results of mechanical thinking on paper is one of the greatest helps to force thinking machinery to systematic and definite action. A designer never thinks very long without drawing something, and the student must bring himself to feel that a drawing in its first sense is a means of helping his own thought, and must freely use it as such.

In its second and final sense, the drawing is an order and specification sheet from the designer to the workman. Design which stops short of exact, finished delineation in the form of working shop drawings is only half done. In fact the possibility of a piece being thus exactly drawn is often the crucial test of its feasibility as a part of a machine. It is easy to make general outlines, but it is not so easy to get down to finished detail. It is safe to say that there is no one thing productive of more trouble, delay and embarrassment, and waste of time and money in the shop, when there need be none from this cause, than a poor detail drawing. The efficiency of the process of design is not fully realized, and failures are often recorded where there should be success, merely because the indefiniteness permitted by the designer in the drawings naturally transmitted itself to the workman, and he in turn produced a part indefinite in form and operation.

The actual process of drawing in the development of a design may be outlined as follows :

Rough sketches merely representing ideas, not drawn to scale, are first made. These are of use only so far as the choice of mechanical ideas is concerned, and to carry preliminary dimensions.

Following these sketches, comes a layout to scale, of the favored sketch, a working out of the relative sizes and location of the parts. This drawing may be of a sketchy nature, carrying a principal dimension here,and there to fix and control the detailed design. In this drawing the design is developed and general detail worked out. The minute detail of the individual parts is, however, left to the subsequent working drawing.

This layout drawing may now be turned over to an expert draftsman or detail designer, who picks out each part, makes an exact drawing of it, studying every little detail of its shape, and finally adds complete dimensions and specifications so that the workman is positively informed as to every point of its construction.

General drawings and cross sections constitute the last step in the process of complete delineation. These show the parts assembled in the complete machine. They also serve a valuable purpose to the draftsman in checking up the dimensions of the detail drawings. Errors which have escaped previous notice are often discovered in this way. The layout, mentioned above, is sometimes finished up into a general drawing; but it is safer to make an entirely new drawing, as changes in detail are often necessary after the layout is made

The four fundamental lines of thought and action noted above may be summarized thus—**"analyze and theorize, modify and delineate."** This is a maxim easy to remember, applicable to every problem in Machine Design, and always provides the answer to the question "What shall I do, how shall I proceed?" by pointing out the proper sequence in the course to be followed.

CONSTRUCTIVE MECHANICS.

Mechanics is a constructive science, its principles lying at the root of the design and operation of all machinery. It is usually taught, however, as an advanced mathematical subject; and the student gets his original conceptions of forces, moments, and beams in the abstract, before he realizes the constructive value of such conceptions. By "Constructive Mechanics" is meant the study of a machine purely from its constructive side, the viewing of the parts with respect to their "mechanics," and satisfying the requirements of the same in form and arrangement.

The student may cultivate this habit of clear, mechanical perception by constantly noting the "mechanics" of the simple structures which he sees in his daily routine of work. Aside from machinery, in which the "mechanics" is often obscure, the world is full of simple examples of natural strength and symmetry, explainable by application of the principles of pure "mechanics."

Posts and pillars are largest at their bases; overhanging brackets or arms are spread out at the fastening to the wall; heavy swinging gates are counter-balanced by a ponderous weight; the old-fashioned well sweep carries its tray of stones at the end, adjusting the balance to a nicety; these are examples of things depending for their form and operation upon the principles of "mechanics." The building of them involved "constructive mechanics," and yet their constructor perhaps never heard of the science, using merely his natural sense of mechanical fitness. Such simple reasoning is, however, Constructive Mechanics.

Forces, Moments, and Beams. Machines are nothing but a collection of (1) parts taking direct stress, or (2) parts acting as loaded beams. Forces acting *witho*
stress on the sustaining part. F

duce a moment; the sustaining member is a beam, and the stress therein depends on the theory of beams, as explained in "Mechanics."

An example of the first is the load on a rope, the force acting without leverage, and the rope therefore having a direct stress put upon it.

An example of the second is a push of the hand on the crank of a grindstone. A moment is produced about the hub of the crank; the arm of the crank is a beam, and the stress at any point of it may be found by the method of theory of beams.

Tension, Compression, and Torsion. The stress induced in the sustaining part, whether tensile, compressive, or torsional, is caused by the application of forces, either acting directly without leverage, or with leverage in the production of moments.

The forces applied from external sources are at constant war with the resisting forces due to the strength of the fibres of the material composing the machine members. The moments of the *external* forces are constantly exerted against and balanced by the moments of the *internal* resistance of the material. Hence, design, from a strength standpoint, is merely a balancing of internal strength against external force. In other words, we may in all cases write a sign of equality, place the applied effort on one side, the effective resistance on the other, and we shall have an equation, which, if capable of solution, will give the proper proportions of the parts considered.

External Force = Internal Resistance.

External Moment = Internal Moment of Resistance.

Expressed in terms of the "Mechanics:"

$$P=AS \qquad (1)$$

$$B \text{ or } T=\frac{SI}{c} \qquad (2)$$

In these formulas, which are perfectly general,

P=direct load in pounds.

A=area of effective material, in square inches.

S=working fibre stress of the material (tensile, compressive, or shearing), in pounds per square inch.

B or T=external moment (bending or torsional), in inch-pounds.

[illegible] direct or polar), of the resisting section.

[illegible] remote fibre of the resisting section from the

P may produce direct tensile, compressive, or shearing stress.

B may produce tensile or compressive stress, and requires use of direct moment of inertia in either case.

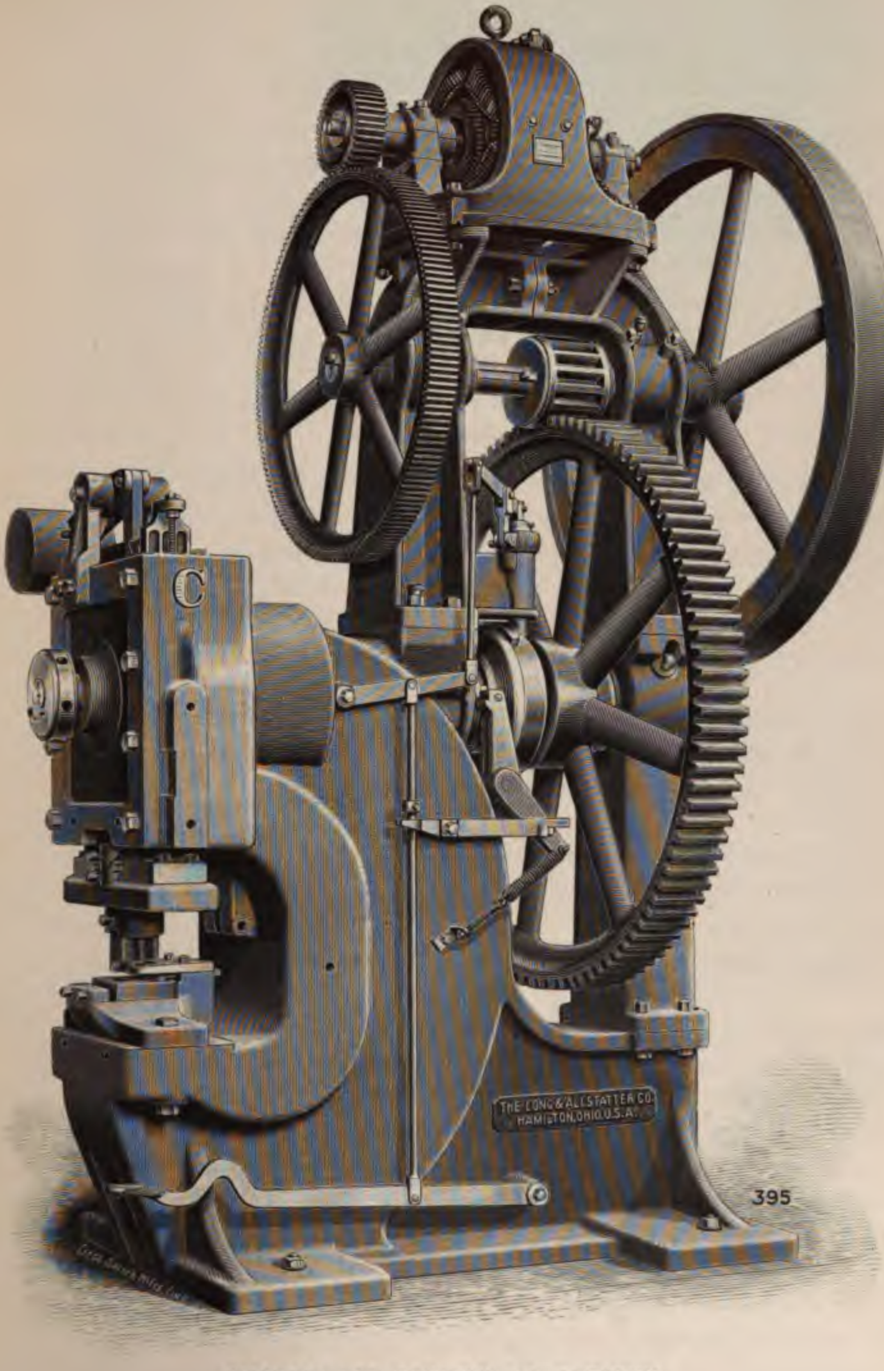
T produces shearing stress, and requires use of polar moment of inertia.

The origin of formula (1) is obvious, the assumption being that the fibre stress is equally distributed to every particle in the area "A."

The development of formula (2) is given in any text-book in Mechanics. It requires the aid of the Calculus, however. Any good handbook gives values for both the direct moment of inertia and the polar moment of inertia for quite a large variety of sections, so that further reference is an easy matter for the student. These values are also obtained through the methods of the Calculus.

The reason for introducing these formulas at this time is to call the attention of the student especially to the fact of their universal and fundamental use in all problems concerning the strength of machine parts. Nearly every computation may be reduced to or expanded from these two simple equations. Many complex combinations occur, of course, which will not permit simple and direct application of these formulas, but the student will do well to place himself in perfect command of these two. Assuming that he is able to analyze forces, and compute the simple moment at the point where he wishes to find the strength of section, the rest is the mere insertion of the assumed working fibre stress of the material in the formula (2) above, and solution for the quantity desired.

When the case is one of combined stress, the relation becomes more complicated and difficult of analysis and solution. The most common case is where bending is combined with torsion, as in the case of a shaft transmitting power, and at the same time loaded transversely between bearings. In fact there are very few cases of shafts in machines, which, at some part of their length, do not have this combined stress. In this case the method of procedure is to find the simple bending moment and the simple torsional moment separately, in the ordinary way. Then the theory of elasticity furnishes us with a formula for an equivalent bending or an equivalent torsional moment which is supposed to produce the same effect upon the fibres of the material [illegible]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action of the two simple moments acting together. In other words, the separate moments combined in action, being impossible of solution in that form, are reduced to an equivalent simple moment and the solution then becomes the same as for the previous case.

These equivalent equations are given below, the subscript "e" being added to express separation from the simple moment:

$$B_e = \frac{B}{2} + \tfrac{1}{2}\sqrt{B^2 + T^2} \qquad (3)$$

$$T_e = B + \sqrt{B^2 + T^2} \qquad (4)$$

B_e and T_e, found from these equations, are the external moments, and are to be equated to the internal moments of resistance of the section precisely as if they were simple bending or torsional moments. Either may be used. For shafts (4) is generally used, being the simpler of the two in form.

FRICTION AND LUBRICATION.

The parts of a machine which have no relative motion with regard to each other are not dependent upon lubrication of their surfaces for the proper performance of their functions. In cases where relative motion does occur, as between a planer bed and its ways, a shaft and its bearing, or a driving screw and its nut, friction, and consequent resistance to motion, will inevitably occur. Heat will be generated, and cutting or scoring of the surfaces will take place if the surfaces are allowed to run together dry.

This difficulty, which exists with all materials, cannot be overcome, for it is a result of roughness of surface, characteristic of the material even when highly finished. The problem of the designer, then, is to take conditions as he finds them, and, as he cannot change the physical characteristics of materials, so choose those which are to rub together in the operation of the machine that friction will be reduced to the lowest possible limit. Now it fortunately happens that there are certain agents like oil and graphite, which seem to fill up the hollows in the surface of a solid material, and which themselves have very little friction on other substances. Hence, if a machine permits by its design an automatic supply of these lubricating agents to all surfaces having motion between them, friction may be reduced to the lowest limit.

If this full supply of lubricant be secured, and the parts still heat and cut, then the fault may be traced to other causes, such as springy surfaces, localization of pressure, or insufficient radiating surface to carry away the heat of friction as fast as it is generated.

Lubricating agents are of a nature running from the solid graphite form to a thick grease, then to a heavy dark oil, and finally to a thin, fluid oil flowing as freely as water. The solid and heavy lubricants are applicable to heavily loaded places where the pressure would squeeze out the lighter oils. Grease, forced between the surfaces by compression grease cups, is an admirable lubricator for heavy machinery under severe service. High-speed and accurate machinery, lightly loaded, requires a thin oil, as the fits would not allow room for the heavier lubricants to find their way to the desired spot. The ideal condition in any case is to have a film of lubricant always between the surfaces in contact, and it is this condition at which the designer is always aiming in his lubricating devices.

Oil ways and channels should be direct, ample in size, readily accessible for cleaning, and distributing the oil by natural flow over the full extent of the surface. Hidden and remote bearings must be reached by pipes, the mouths of which should be clearly indicated and accessible to the operator of the machine. Such pipes must be straight, if possible, and readily cleaned.

There is one practical principle affecting the design of methods of lubrication of a machine which should be borne in mind. This is, "Neglect and carelessness by the operator *must* be provided for." It is of no use to say that the ruination of a surface or hidden bearing is due to neglect by the operator, if the means for such lubrication are not perfectly obvious. This is "locking the door after the horse is stolen." The designer has not done his duty until he has made the scheme of lubrication so plain that every part *must* receive its proper supply of oil, except by gross and willful negligence, for which there can be no possible just excuse.

WORKING STRESSES AND STRAINS.

Some persons object to the use of these terms, as one is frequently used for the other, and misunderstanding results. This is doubtless true; but the student may as well learn the true relation of the terms once for all, because he will frequently run across them in his reading and reference work, and should interpret them rightly. The strict relation of the two is as follows:

Stress is the internal force in a piece resisting the external force applied to it. A weight of ten pounds hanging on a rope produces a *stress* of ten pounds in the rope.

Strain is the change of shape, or deformation, in a piece resisting an external force applied to it. If the above weight of ten pounds stretches the rope $\frac{1}{4}$ inch, the *strain* is $\frac{1}{4}$ inch.

Unit stress is stress per unit area, e. g., per square inch.

Unit strain is strain per unit length, e. g., per inch length.

In the above case, if the rope were $\frac{1}{2}$ square inch in area and 30 inches long, the unit stress, or intensity of stress, is $10 \div \frac{1}{2} = 20$ pounds per square inch; the unit strain is $\frac{1}{4} \div 30 = \frac{1}{120}$ inch per inch.

When stress is induced in a piece, the strain is practically proportional to the stress for all values of the stress below the elastic limit of the material; and when the external load is removed the strain will entirely disappear, or the recovering power of the material will restore the piece to the original length.

Illustrating by the case above, on the supposition that the elastic limit has not been reached by the stress of 20 pounds per square inch, if the load of 10 pounds were taken off, the $\frac{1}{4}$-inch strain would disappear and the rope return to its original length; if the load were changed to $\frac{1}{2}$ of 10 pounds, or 5 pounds, the strain would be $\frac{1}{2}$ of $\frac{1}{4}$ inch, or $\frac{1}{8}$ inch.

Now it is found that if we wish a piece to last in service for a long time without danger of breakage, we must not permit it to be stressed anywhere near the elastic limit value. If we do, although it will probably not break at once, it is in a dangerous condition, and not well suited to its requirements as a machine member. The technical name for this weakening effect is "fatigue." It is further found that the fatigue due to this repeated stress is reached at a lower limit when the stress is alternating in character than when it is not. In other words, if we first pull on a piece and then push on it, we shall first have the piece in tension and then in compression; this alternation of stress repeated to near the elastic limit of the material will fatigue it, or wear out the fibres, and it will finally fail. If, however, we first pull on the piece with the same force as before, and then let go, we shall first have the piece in tension and then entirely relieved; such repetition of stress will finally "fatigue" the material, but not so quickly as in the first case. Experiments indicate that it may take twice as many applications in the latter case as in the former.

The working stress of materials permissible in machines is based on the above facts. The breaking strength divided by a liberal factor of safety will not necessarily give a desirable working stress. The question to be answered is, "Will the assumed working fibre stress permit an indefinite number of applications of the load without fatiguing the material?"

Hence we see that the same material may be safely used under different assumptions of working stress. For example, a rotating shaft, heavily loaded between bearings. acts as a beam which in each revolution is having its particles subjected, first to a maximum tensile stress, and then to a maximum compressive stress. This is obviously a very different stress from that which the same piece would receive if it were a pin in a bridge truss. In the former we have a case where the stress on each particle reverses at each revolution, while in the latter we have merely the same stress recurring at intervals, but never becoming of the opposite character. For ordinary steel, a value of 8,000 would be reasonable in the former case, while in the latter it may be much higher with safety, perhaps nearly double.

From the facts stated above, it is evident that exact values for working fibre stress cannot be assumed with certainty and applied broadly in all cases. If the elastic limit of the material is definitely known we can base our working value quite surely on that.

With but a general knowledge of the elastic limit, ordinary steel is good for from 12,000 to 15,000 pounds per square inch non-reversing stress, and 8,000 to 10,000 reversing stress. Cast iron is such an uncertain metal on account of its variable structure that stresses are always kept low, say from 3,000 to 4,000 for non-reversing stress, and 1,500 to 2,500 for reversing stress.

With these values as a guide, and the special conditions controlling each case carefully studied, reasonable limits may be assigned for working stress, not only of steels, various grades of cast iron, and mixtures of the same, but of other alloys, brass, bronze, etc. Gun metal, semi-steel, and bronze are intermediate in strength between cast iron and steel. Data on the strength of materials are available in any of the handbooks, and should be consulted freely by the student. They will be found somewhat conflicting, but will assist the judgment in coming to a conclusion.

Application to Practical Case. In actual practice the only information which the designer has, upon which to base his design, is the object to be accomplished. He must choose or originate suitable devices, develop the arrangement of the parts, make his own assumptions regarding the operation of the machine, then *Analyze and Theorize, Modify and Delineate* each detail as he meets it.

This, it will be found, is a very different matter from taking some familiar piece of machinery, such as a pulley, or a shaft, or a gear, as an isolated case, the load being definitely given, and proceeding with the design. This is easily done, but is only half the problem, for machine parts, such as pulleys, gears, and shafts, do not confront the designer tagged or labeled with the conditions they are to meet. He is to provide parts to meet the specific conditions, and it is as much a part of his designing method to know how to attack the design of a machine as it is to know how to design the parts in detail after the attack has reduced the members to definitely loaded structures. The whole process must be gone through, the preliminary sketches, calculations, and layout, all of which precede the detail design and working drawings; and no step of the process can be omitted.

It is for this reason that the present case used for illustration is carried out quite thoroughly. The student should make himself familiar with every step of the designing method as applied to this simple case of design. More complex problems, handled in the same way, will simplify themselves; and when the point is reached where confidence exists to take hold of the design of any machine, however unfamiliar its object may be, or however involved its probable detail appears, the student has become the true designer. It is the knowing how to attack a problem, to start definite work on it, to go ahead boldly, confident that the method applied will produce results, that gives command of the design of machinery and wins engineering success.

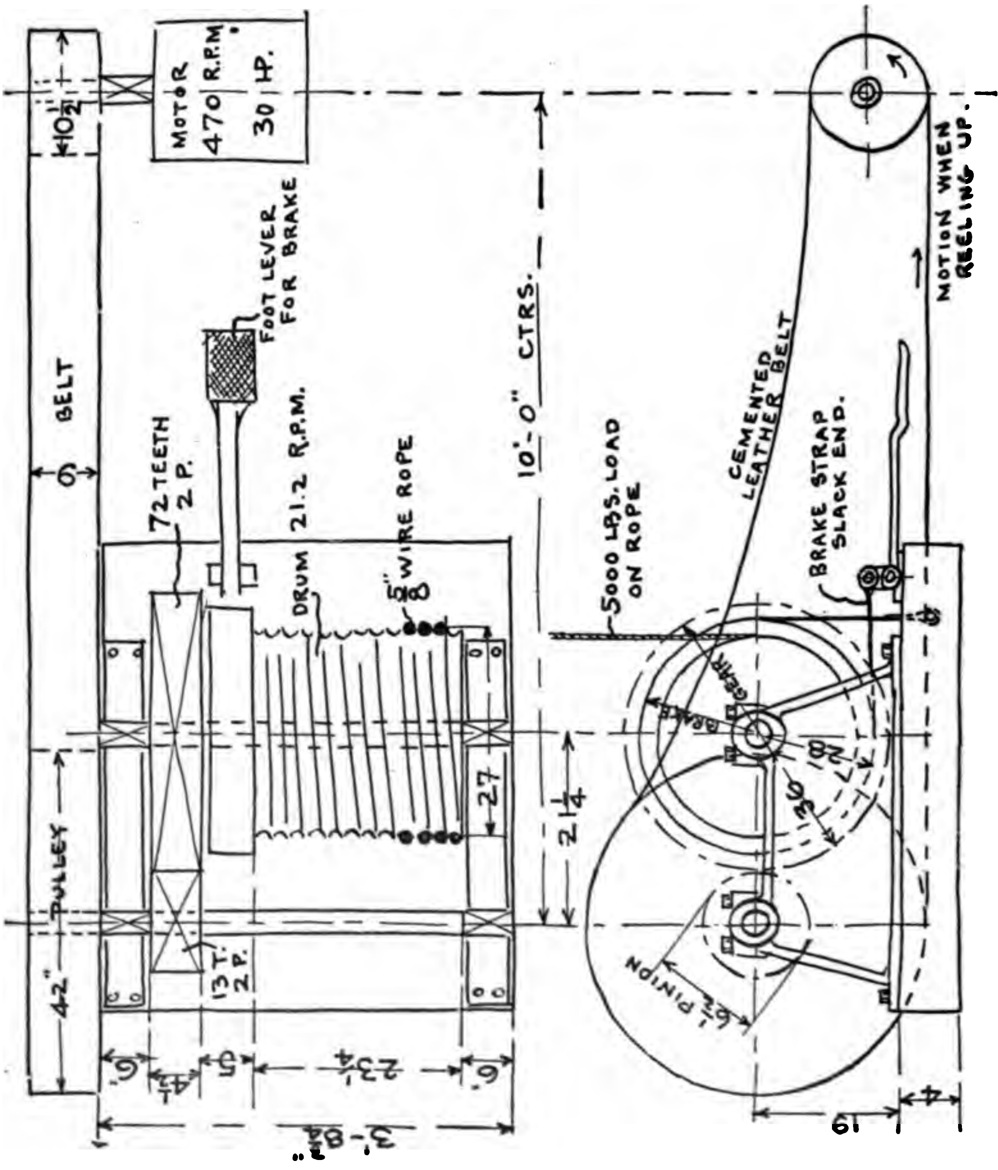


Fig. 1.

The special case which has been chosen to illustrate the application of the principles stated in the foregoing pages is ideal, in that it does not represent any actual machine at present in operation. Probably builders of hoisting machinery have devices which would improve the machine as shown. In detail, as well as arrangement, they could doubtless make criticism as manufacturers. The arrangement as shown is merely intended to bring out in simplest form the common elements of transmission machinery as parts of some definite machine, instead of as isolated details. The design is one entirely possible, practical, and mechanical, but special attention has been paid to simplicity in order to enable the student to follow the method closely, for the *method* is the chief thing for him to acquire.

The student is expected to refer constantly to Part II for a more formal and general discussion of the simple machine elements involved in the case considered. Part II is intended to be a simplified and condensed reference book, carried out in accordance with the method of machine design as specified in Part I. The student should not wait until he has completed the study of this part before taking up Part II, for the latter is intended for use with the former in the solution of the problems.

In the case of power transmission about to be studied, the running, conversational method employed assumes that the student is in possession of the matter in Part II on the subject considered. Thus, in the design of the pulley, reference to the subject of "Pulleys" in Part II is necessary to follow the train of calculation; in designing the gear, consult "Gears;" in calculating size of shafts, see "Shafts," etc., etc.

Problem. A machine is to be designed to be set on the floor of a building to drive a wire rope falling from the overhead sheaves of an elevator or hoist. Without regard to details of this overhead arrangement, for its design would be a separate problem, suppose that the data for the rope are as follows:

Load on rope	5,000 pounds.
Speed of rope	150 feet per minute.
Length of rope to be reeled in	200 feet.

We shall further assume that the driving power is to be an electric motor belted to the machine, that the required speed reduction can be satisfactorily obtained by a single pair of pulleys and one pair of gears, and that a plain band brake is to be applied to the drum.

With this data we shall proceed to work out the detail design of the machine.

Preliminary Sketch. The first thing to do is to sketch roughly the proposed arrangement of the machine.

This might appear like Fig. 1 except that it would have no dimensions in addition to the data given above. If the scheme seems suitable, the next step is to make such preliminary calculations as will give further data, exact or closely approximate sizes, to be put at once on the sketch, to outline the future design.

Rope and Drum. Referring to tables of strength of wire rope (Kent's Pocket Book gives the manufacturers' list), we find that a $\frac{5}{8}$-inch cast-steel rope will carry 5,000 pounds safely, and that the proper size of drum to avoid excessive bending of the rope around it is 27 inches diameter. Allowing $\frac{1}{8}$ inch between the coils as the rope winds on the drum, the pitch of coil will be $\frac{3}{4}$ inch as shown in sketch, Fig. 2. The length of one complete coil is, practically, $\frac{27 \times 3.1416}{12}$ $=7.07$ feet. To provide for 200 feet will require $\frac{200}{7.07}=28+$coils. To be safe, let us provide for 30 coils, for which a length of drum $(30 \times \frac{3}{4})+\frac{3}{4}=23\frac{1}{4}$ inches is required.

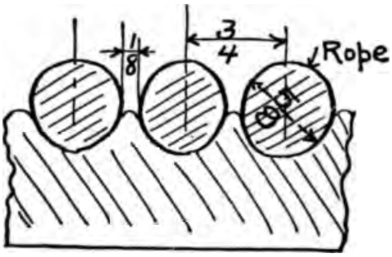


Fig. 2.

The space for brake strap may be assumed at 5 inches, and the thickness to provide necessary strength determined later in the design. The frictional surface of the strap may be of basswood blocks, say $1\frac{1}{4}$ inches thick, screwed to the metal band. The diameter of brake surface may be 28 inches.

Driving Gears. The size of drum gear evidently depends upon the method of fastening to the drum, and, other things being equal, should be kept as small as possible. One way would be to key the gear on the outside of the drum, another to bolt the gear to the end of the drum. The latter has the advantage that a standard gear pattern can be used with the slight change of addition of bolt flange on the arms. This makes a simple, direct, and strong drive, the bolts being in shear.

Sketching this arrangement as the preferred one (Fig. 2A), it is evident that the diameter of the gear should be at least as large as the drum in order to keep the tooth load down to a reasonable figure. On the other hand, if made too large, it spreads out the machine and destroys its compactness. As a diameter of 36 inches is not excessive, let us assume this, and see if a desirable proportion of gear tooth can be found to carry the load.

For a pitch diameter of 36 inches there will be a theoretical load of $\frac{5,000 \times 27}{36} = 3,750$ pounds at the pitch line. But the load on the tooth must not only impart a pull of 5,000 pounds to the rope, but must overcome friction between the gear teeth in action, also between the drum shaft and its bearings. Assuming the efficiency between the rope and tooth load to be 95 per cent, the net load, therefore, which the tooth must take is $\frac{3,750}{.95} = 3,947$, say 4,000 pounds.

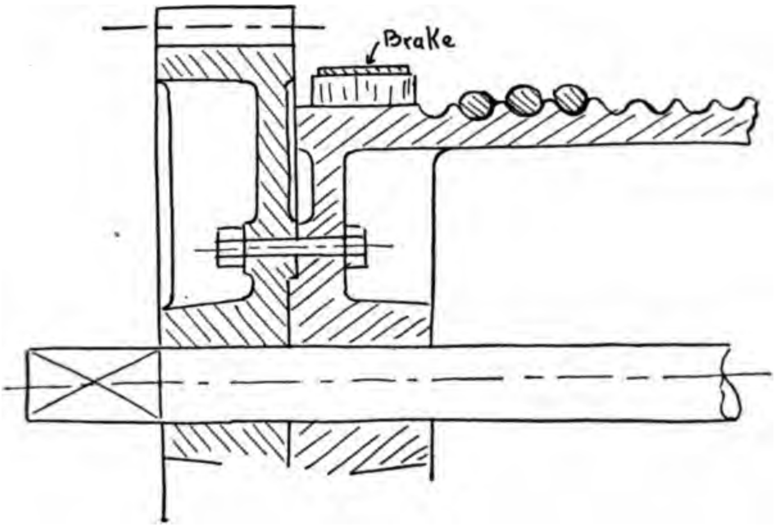


Fig. 2A.

Assuming involute teeth, and applying the "Lewis" formula, (Part II, "Gears"):

$$W = s \times p \times f \times y$$

$$4{,}000 = 6{,}000 \times p \times f \times .116$$

$$p \times f = \frac{4{,}000}{6{,}000 \times .116} = 5.7 \text{ inches}$$

$W = 4{,}000$
$s = 6{,}000$
$y = .116$ (number of teeth assumed at 75)
$p =$ circular pitch
$f =$ face of gear

Let $f = 3\,p$ (a reasonable proportion for machine-cut teeth).

Then $3 \times p^2 = 5.7$

$p^2 = 1.9$

$p = \sqrt{1.9} = 1.378$ inches

The diametral pitch corresponding to this is

$$\frac{3.1416}{1.378} = 2.28$$

which is just between the regular standard pitches, 2 and $2\frac{1}{2}$, for which stock cutters are made. To be safe, let us take the coarser pitch, which is 2. The circular pitch corresponding to this is $\frac{3.1416}{2} = 1.57$, and making the face about three times the circular pitch gives

$$3 \times 1.57 = 4.71, \text{ say } 4\tfrac{1}{2} \text{ inches.}$$

The number of teeth in the gear is then $36 \times 2 = 72$. Referring to the value assumed for the tooth factor in calculation above, it is seen that y was based on 75 as the number of teeth, which is near enough to 72 to avoid the necessity of further checking the result.

The pinion to mesh with this gear should be as small as possible in order to get a high-speed ratio between pinion shaft and drum, otherwise an excessive ratio will be required in the pulleys, making the large one of inconvenient size. Small pinions have the teeth badly undercut and therefore weak, 13 teeth being the lowest limit usually considered desirable, for that reason. Choosing that number, we have a pitch diameter of $\frac{13}{2} = 6.5$ in., which is probably ample to take the shaft and key, and still leave sufficient stock under the tooth for strength. If made of cast iron, however, the pinion teeth, on account of the low number, will be narrower at the root than those of the gear of 72 teeth. Yet it was upon the basis of the latter that the pitch was chosen, for it will be remembered that the value of y in the formula was taken at .116. Hence the pinion will be weaker than the gear unless we make it of stronger material than cast iron, of which the large gear is supposed to be made. Steel lends itself very readily to this requirement; and in practice, pinions of less than 20 teeth are usually made of this material, hence we shall specify the pinion to be of steel.

Pulleys. The question now is whether or not we can get a suitable ratio in the pulleys without making the large one of inconvenient size, or giving the motor too slow speed for an economical proportion.

Suppose we limit ourselves to a diameter of 42 inches for the large pulley, and try a ratio of 4 to 1; this will give a diameter for the small pulley of $\frac{42}{4}=10\frac{1}{2}$ inches. We shall then have

Total ratio between drum and motor........ $\frac{72}{13}\times 4=\frac{288}{13}=22.2$

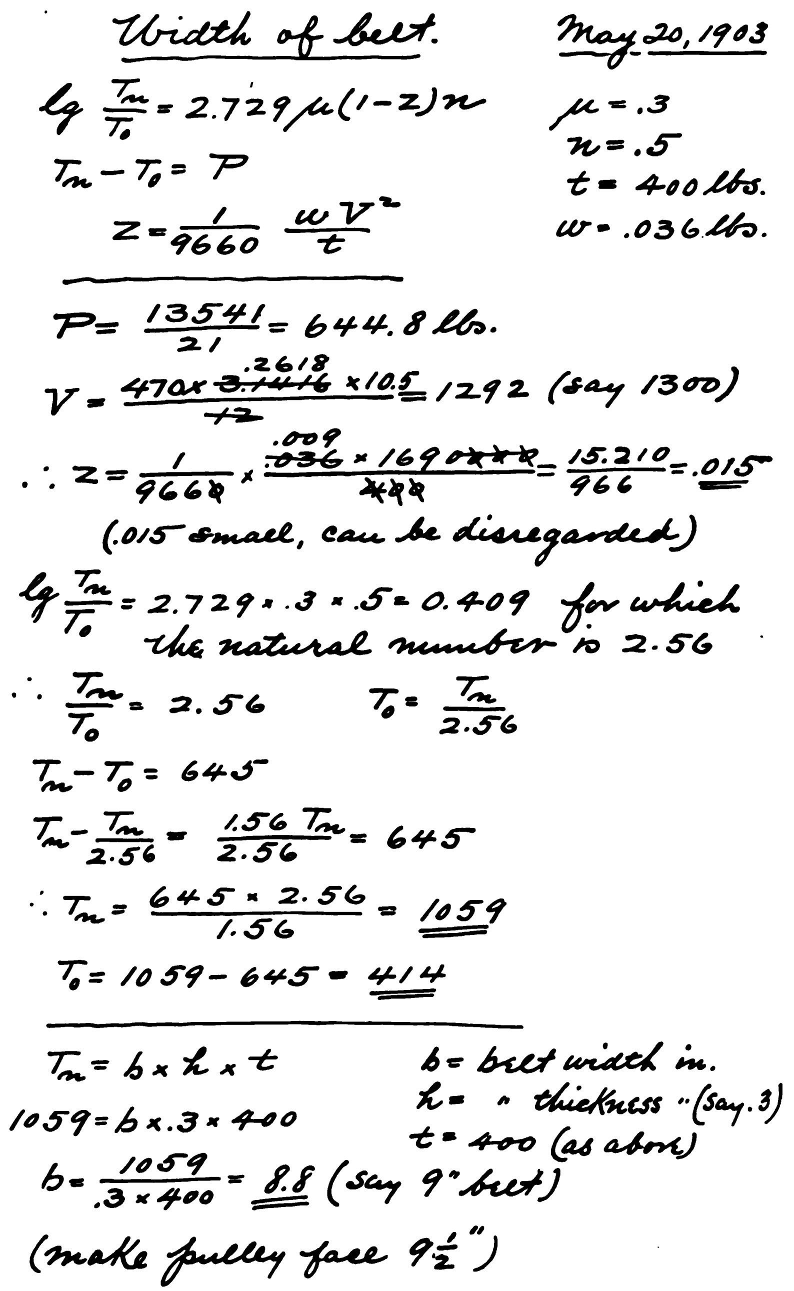
Rev. per min. of drum to give 150 f. p. m. of rope.................................. $\frac{150}{7.07}=21.2$

Rev. per min. of motor......................22.2 × 21.2=470

Horse-power of motor at 80 per cent efficiency $\frac{150\times 5{,}000}{33{,}000\times .80}=30$

A 30 H. P. motor running 470 r. p. m. would be classed as a slow speed motor and would be a heavier machine and cost more than one of higher speed. It will be noticed, however, that the diameter of the small pulley is already quite reduced, and it is hardly desirable to decrease it still further. Neither can we increase the large pulley, as we have already set the limit at 42 inches. Hence, for our present problem we cannot improve matters much without increasing the size of the large gear, which is undesirable, or putting in another pair of gears, which is contrary to the conditions of the problem. As such a motor is perfectly reasonable, we shall assume it to be chosen for the purpose.

In commercial practice it would be well to pick out some standard make of motor of the required horse-power, note the speed as specified by the makers, and then, if possible, suit the ratio in the machine to this speed. It is always best to use standard machinery, if possible, both from the standpoint of first cost, as well



Width of belt.

May 20, 1903

$$lg\frac{T_n}{T_0} = 2.729\mu(1-z)n$$

$$T_n - T_0 = P$$

$$z = \frac{1}{9660}\,\frac{wV^2}{t}$$

$\mu = .3$

$n = .5$

$t = 400$ lbs.

$w = .036$ lbs.

$$P = \frac{13541}{21} = 644.8 \text{ lbs.}$$

$$V = \frac{470 \times \overset{.2618}{\cancel{3.1416}} \times 10.5}{\cancel{12}} = 1292 \text{ (say 1300)}$$

$$\therefore z = \frac{1}{966\cancel{0}} \times \frac{\overset{.009}{\cancel{.036}} \times 1690\cancel{000}}{\cancel{400}} = \frac{15.210}{966} = \underline{\underline{.015}}$$

(.015 small, can be disregarded)

$$lg\frac{T_n}{T_0} = 2.729 \times .3 \times .5 = 0.409$$ for which the natural number is 2.56

$$\therefore \frac{T_n}{T_0} = 2.56 \qquad T_0 = \frac{T_n}{2.56}$$

$$T_n - T_0 = 645$$

$$T_n - \frac{T_n}{2.56} = \frac{1.56\,T_n}{2.56} = 645$$

$$\therefore T_n = \frac{645 \times 2.56}{1.56} = \underline{\underline{1059}}$$

$$T_0 = 1059 - 645 = \underline{\underline{414}}$$

$$T_n = b \times h \times t$$

$$1059 = b \times .3 \times 400$$

$b =$ belt width in.

$h =$ " thickness " (say .3)

$t = 400$ (as above)

$$b = \frac{1059}{.3 \times 400} = \underline{\underline{8.8}} \text{ (say 9" belt)}$$

(make pulley face $9\frac{1}{2}$")

Fig. 3.

as ease of replacing worn parts. Machinery ordered special is expensive in first cost of designing, patterns, and tools, and extra spare parts for emergency orders are not often kept on hand.

Tabulation of Torsional Moments. For future reference, it is desirable at this point to tabulate the torsional moment, or torque, about each of the three shaft axes, assuming reasonable efficiencies for the various parts, as follows:

Efficiency between drum and gear tooth	95 per cent
Efficiency between drum and pinion shaft	90 per cent
Efficiency between drum and motor shaft	80 per cent

TABLE OF TORSIONAL MOMENTS.

Axis.	Inch Lbs. Torque at 100 Per Cent Efficiency.	Inch Lbs. Torque, Efficiency as Above.
Drum	$5{,}000\times\frac{27}{2}$ =67,500	$\frac{67{,}500}{.95}=71{,}052$
Pinion	$5{,}000\times\frac{27}{2}\times\frac{13}{72}$ =12,187	$\frac{12{,}187}{.90}=13{,}541$
Motor	$5{,}000\times\frac{27}{2}\times\frac{13}{72}\times\frac{10.5}{42}=$ 3,047	$\frac{3{,}047}{.80}=3{,}809$

This means that the motor develops a torque of 3,809 inch-pounds delivering to pinion shaft 13,541 inch-pounds, and to drum 71,052 inch-pounds.

Width of Belt. The page of calculation for belt width is reproduced in Fig. 3.

The calculation as given is strictly scientific, based on the working strength of a cemented joint (t=400 lbs. per square inch). This is a favorable situation for the use of a cemented joint, because it is easy to provide means of adjusting the belt tension by placing the motor on a sliding base. Otherwise a laced joint could be used, requiring relacing when the belt slackens through its stretch in service. Under the assumption that a double *laced* belt is used, the empirical formula below is one often applied:

$$\text{H. P.}=\frac{w\times \text{V}}{540}=\frac{w\times 1{,}300}{540}=30$$

This gives $w=\frac{540\times 30}{1{,}300}=12{\cdot}4$ inches (say 12 inches).

It should be remembered that this value is purely empirical; it applies to a *laced* joint, and could not be expected to check the value of 9 inches obtained by the first computation for a cemented joint. It is fairly in proportion. For the quite definite service required of the belt in the present case, the width of 9 inches is doubtless sufficient, considering the cemented joint.

Length of Bearings. Considerable latitude in choice of length of bearings is permissible, especially in such slow-speed machinery. There is probably little danger from heating, and the question then becomes one of wear. It is better in such cases as the one in question, to choose boldly a length which seems to be reasonable and proceed with the design on that basis, even if the length be later found out of proportion to the shaft diameter, than to waste too much time in the preliminary calculation over the exact determination of this question. Probably in most cases of commercial practice the existence of patterns, or some other practical consideration, will decide the limits of length.

In the present instance it seems reasonable that a length of 6 inches would fill the requirement for the worst case, that of the drum shaft, and it is obvious that the bearings for the pinion shaft would naturally be of the same length on account of being cast on the same bracket, and faced at the same setting of the planer tool.

Height of Centers. The large pulley should naturally swing clear of the floor. This will require, say, a total height of 23 inches, out which we may take 4 inches for the base, leaving 19 inches as the height, center of bearing to base of bracket.

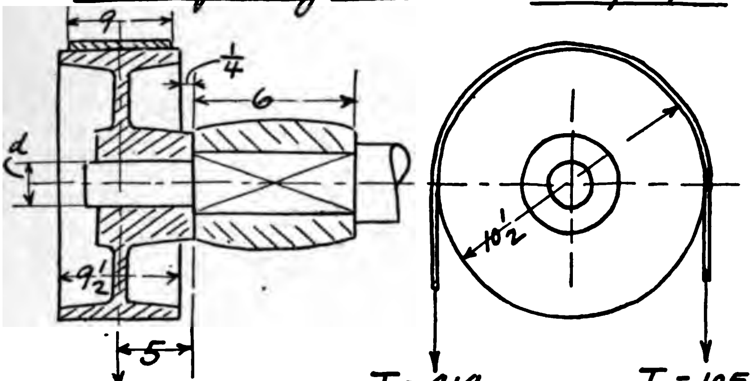
Data on Sketch. The data as found above should now be put on the sketch previously made; it will then have the appearance shown in Fig. 1.

This sketch is now in form to control all the subsequent detail design, and it is expected that the figured dimensions as shown can be maintained. It is impossible to predict this with positiveness, however, as in the working out of the minor details certain changes may be found desirable, when, of course, they should be made.

The shaft sizes do not appear on this sketch, hence before proceeding further the several shaft diameters must be calculated.

Sizes of Shafts. The calculations of the shaft diameters are good instances of systematic engineering computations, hence they are reproduced in the exact form in which they were made. The student should learn a valuable lesson in making and recording calculations by following these carefully. Note that each set of figures is independent, both in the statement of given data, as well as in the actual computation. Observe how easy it would be for the author of these figures or anyone else to check them even after

Small pulley bore. May 21, 03



$T_x + T_0 = 1473$ $T_0 = 414$ $T_x = 1059$

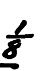
$B = 1473 \times 5 = 7365$

$T = 645 \times 5.25 = 3386$

$T_e = B + \sqrt{B^2 + T^2}$

$= 7365 + \sqrt{7365^2 + 3386^2}$

$= 7365 + 8120 = 15485$



$T_e = \frac{sI}{c} = \frac{sd^3}{5.1}$ Let $s = 8000$

$15485 = \frac{8000\,d^3}{5.1}$

$d^3 = \frac{15485 \times 5.1}{8000} = 9.872$

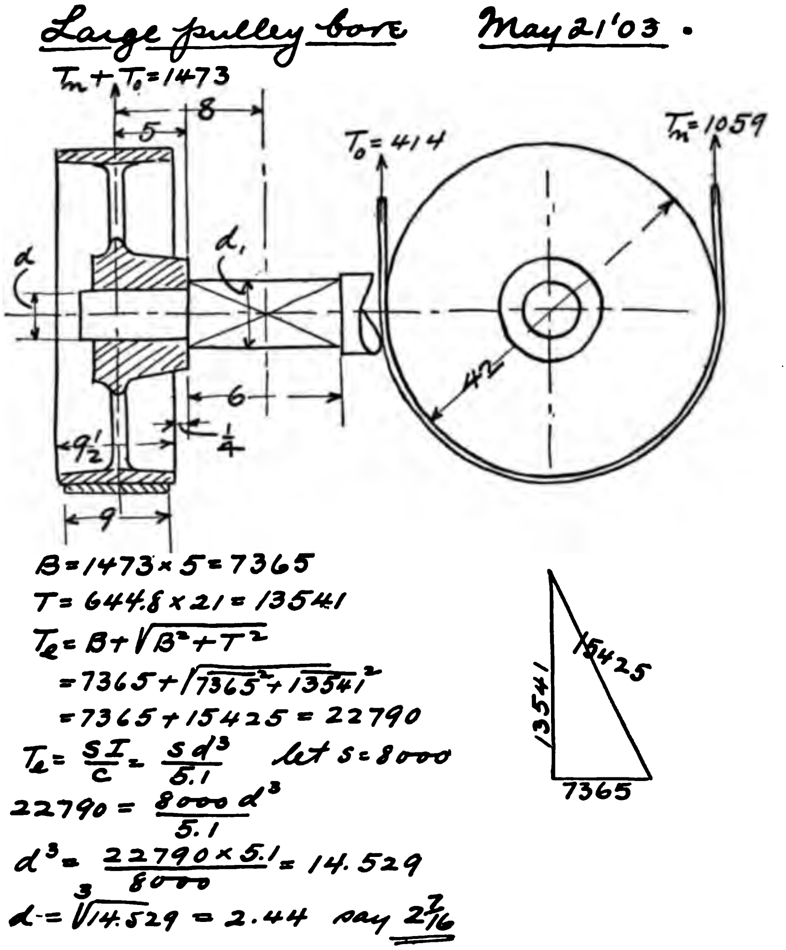
$d = \sqrt[3]{9.872} = 2.14$ say $2\frac{1}{8}$

Fig. 4.

a long lapse of time. If the machine should unexpectedly fail in service the figures are always available to prove or disprove theoretical weakness. The right triangles merely indicate that the value of $\sqrt{B^2+T^2}$ was found by the graphical method suggested in

Part II, "Shafts," the figures being put on the triangle as a simple and direct way of recording both process and result.

Attention is especially called to the fact that in the pinion shaft the size is changed for each piece upon the shaft. This is done partly because it is desired to show the student that the shaft at each of these points should be theoretically of different size. It is also done because as a practical feature of construction it is a good plan to change the size when the fit changes, partly for reasons of production in the shop, partly for ease in slipping pieces



$B = 1473 \times 5 = 7365$

$T = 644.8 \times 21 = 13541$

$T_e = B + \sqrt{B^2 + T^2}$

$= 7365 + \sqrt{7365^2 + 13541^2}$

$= 7365 + 15425 = 22790$

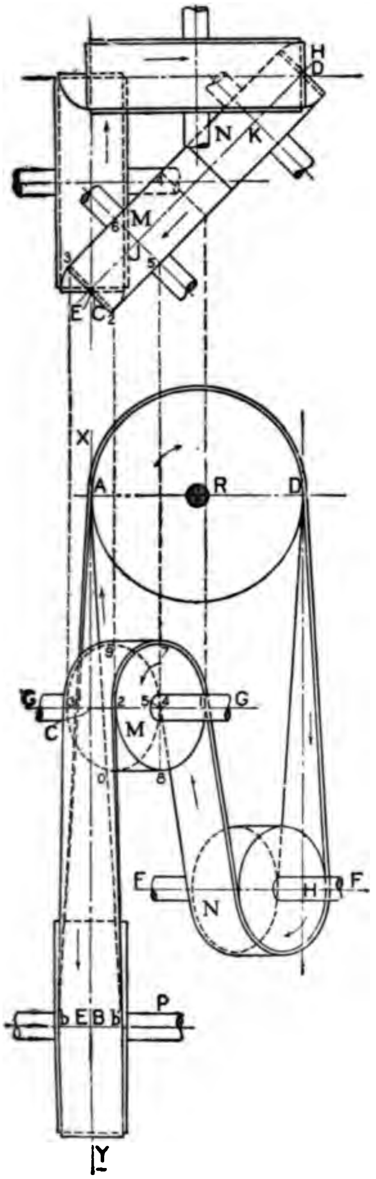
$T_e = \frac{SI}{c} = \frac{S d^3}{5.1}$ let $S = 8000$

$22790 = \frac{8000 d^3}{5.1}$

$d^3 = \frac{22790 \times 5.1}{8000} = 14.529$

$d = \sqrt[3]{14.529} = 2.44$ say $2\frac{7}{16}$

Fig. 5.


H
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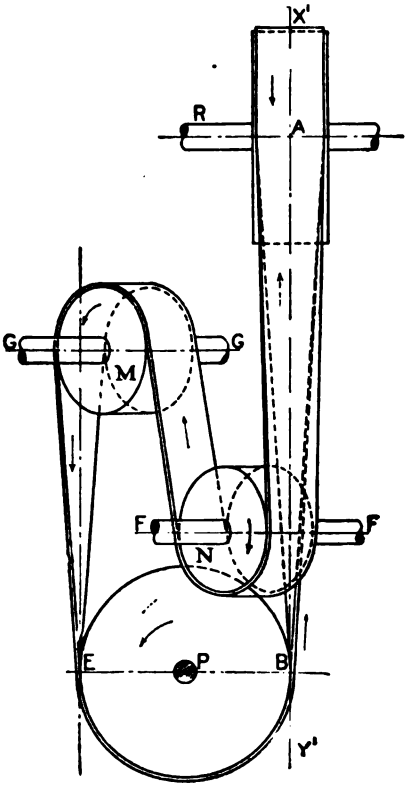
X'
R
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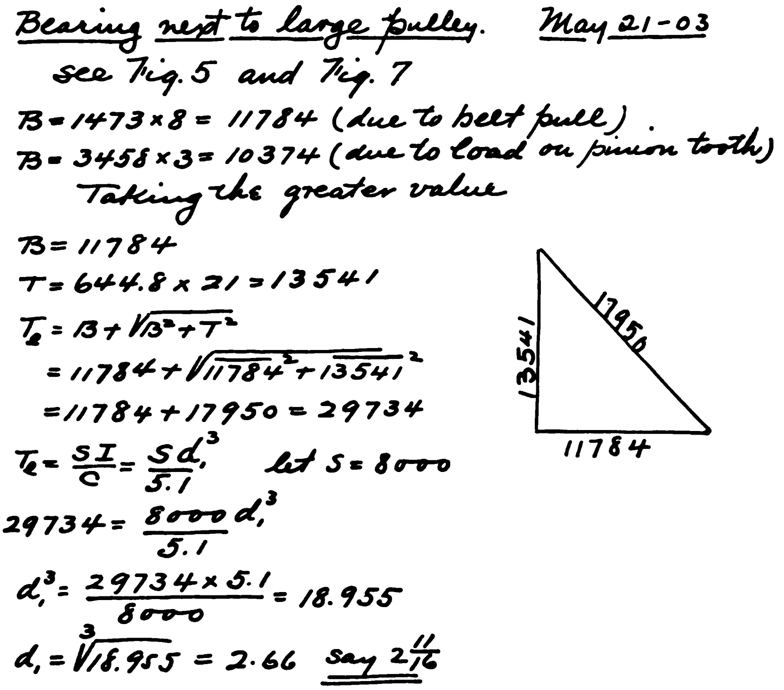
P
B
Y'

freely endwise on the shaft until they reach their proper fit and location in the assembling of the machine.

This should not be taken as an absolute requirement in any sense. A straight shaft would be satisfactory in the present case; but the shouldered shaft is a little better construction, in a mechanical sense, and does not cost much more. Hence it is used. For the drum the straight shaft seems to answer the requirement well enough.



Bearing next to large pulley. May 21-03

see Fig. 5 and Fig. 7

$B = 1473 \times 8 = 11784$ (due to belt pull).

$B = 3458 \times 3 = 10374$ (due to load on pinion tooth)

Taking the greater value

$B = 11784$

$T = 644.8 \times 21 = 13541$

$T_e = B + \sqrt{B^2 + T^2}$

$= 11784 + \sqrt{11784^2 + 13541^2}$

$= 11784 + 17950 = 29734$

$T_e = \frac{SI}{c} = \frac{S d_1^3}{5.1}$ let $S = 8000$

$29734 = \frac{8000 \, d_1^3}{5.1}$

$d_1^3 = \frac{29734 \times 5.1}{8000} = 18.955$

$d_1 = \sqrt[3]{18.955} = 2.66$ say $2\frac{11}{16}$

Fig. 6.

Small Pulley Bore. Fig 4.

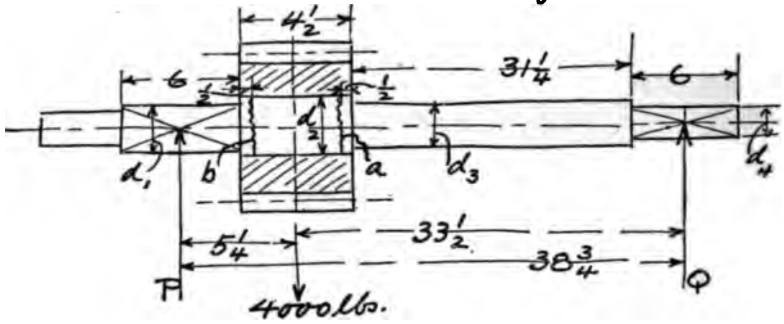
Large Pulley Bore. Fig. 5.

Bearing Next to Large Pulley. Fig. 6.

The diameter, $2\frac{1}{16}$, as calculated, is based on the supposition that the greatest bending moment is caused by the belt pull on the overhanging pulley, that is, by the forces existing at the left-hand side of the center of the bearing.

But the pinion tooth load produces a heavy bending on the shaft in the bearing, the shaft in this case acting as a beam sup-

Pinion Bore May 21 '03



$P \times 38.75 = 4000 \times 33.5$ (moments about Q)

$$P = \frac{4000 \times 33.5}{38.75} = 3458$$

$$Q = 4000 - 3458 = 542$$

$B = 542 \times 31.75 = 17208$ (due to Q)

$B = 3458 \times 3.5 = 12103$ (due to P)

Taking the greater value

$B = 17208$

$T = 13541$ (as before)

$$T_e = B + \sqrt{B^2 + T^2}$$

$$= 17208 + \sqrt{17208^2 + 13541^2}$$

$$= 17208 + 21900 = 39108$$

$T_e = \frac{SI}{c} = \frac{Sd_2^3}{5.1}$ let $S = 8000$

$$39108 = \frac{8000\, d_2^3}{5.1}$$

$$d_2^3 = \frac{39108 \times 5.1}{8000} = 24.928$$

$d_2 = \sqrt[3]{24.928} = 2.92$ say $2\frac{15}{16}$

Fig. 7.

ported at the two bearings and having the tooth load applied as shown. If this latter effect be greater than the former, that is, if the bending moment produced by the pinion tooth load be greater than the bending moment produced by the belt pull, then the diameter must be increased to satisfy the latter case. As is seen by the second calculation of Fig. 6, this is not the case, and the diameter stands at $2\frac{1}{16}$ as made.

Pinion Bore. Fig. 7. The pinion being a driving fit upon the shaft, reinforces the shaft to such an extent that it is hardly possible for the shaft to break off very far inside the face of the pinion; but it is quite possible that the metal of the pinion may give enough, or be a little free at the ends of the hole, so that the shaft may be broken off, say $\frac{1}{2}$ inch inside the face. In this case, it may fail from the moment of the force at the left-hand bearing or of that at the right. It may fail then at (a) or (b), depending on which section has the greater bending moment. Trying both, it is seen by the calculation that the right-hand moment is the controlling one, and it, therefore, is used.

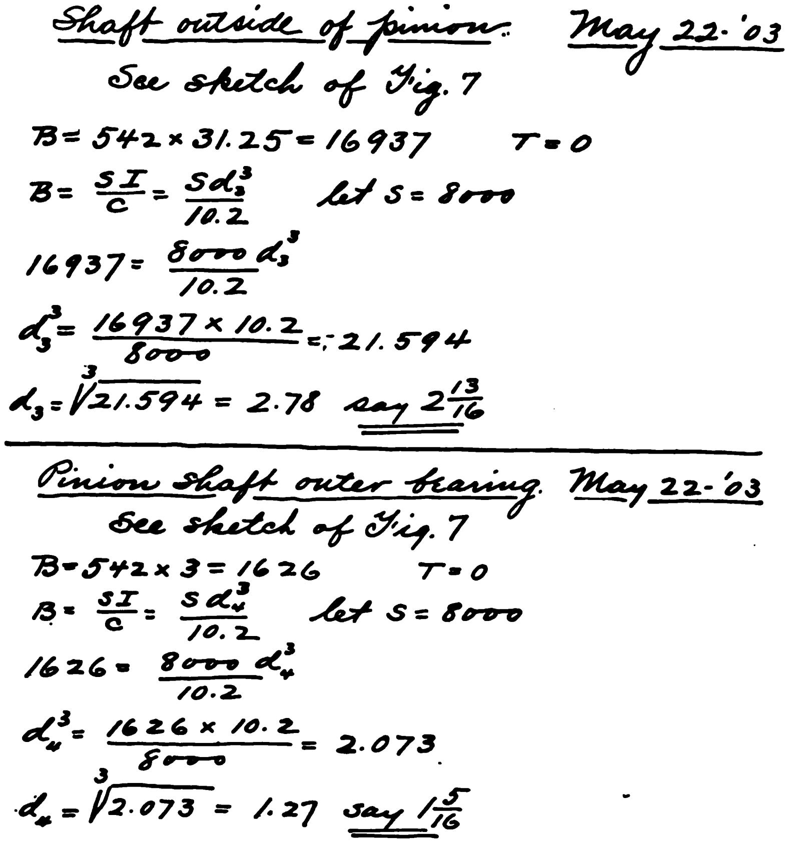
Shaft Outside of Pinion. Fig. 8. As there is no power transmitted through this portion of the shaft, there is no torsional moment in it, and the bending moment remains practically the same as inside the pinion.

The size figures about $2\frac{13}{16}$, but since there is no use in turning off material just to reduce the size to this, it is well to make it $2\frac{7}{8}$, or just smaller than the fit in the pinion.

Pinion Shaft Outer Bearing. Fig. 8. This diameter, of course, figures small, as there is no torsion in it, and the bending moment is not heavy. The practical question comes in, however, whether it is advisable to make the outer bracket different from the inner one just on account of this bearing. The commercial answer to this would probably be "No," hence the size as figured next to the pinion will be maintained ($2\frac{1}{16}$).

Drum Shaft. Fig. 9. In this case, as previously inferred, the simplest thing to do is to use a piece of straight cold-rolled steel, and make both bearings alike, the size being determined according to the worst case of loading which can occur as the rope travels from end to end of the drum. This case is evidently when the rope is at the end of its travel close to the brake, for at that time both the load on the rope and the load on the pinion tooth which is driving it are exerted upward, and produce the greatest reaction at the bearing next to the gear. The analysis of the forces for this condition is shown in Fig. 9.

Other conditions of loading would be when the brake is on and the tooth load relieved, but then the resultant of the brake strap tensions would be diagonally downward and would reduce rather than add to the rope load. Again, when the rope is at the end of the drum farthest from the gear, the load on it and the load on the pinion tooth are both exerted upward as before, but the reaction cannot be as great as in the case of Fig. 9, because the tooth load is still concentrated at the other end of the shaft and produces a relatively small reaction at the rope end.



Shaft outside of pinion. May 22-'03

See sketch of Fig. 7

$B = 542 \times 31.25 = 16937$ $T = 0$

$B = \frac{SI}{c} = \frac{Sd_3^3}{10.2}$ let $S = 8000$

$16937 = \frac{8000\, d_3^3}{10.2}$

$d_3^3 = \frac{16937 \times 10.2}{8000} = 21.594$

$d_3 = \sqrt[3]{21.594} = 2.78$ say $2\frac{13}{16}$

Pinion shaft outer bearing. May 22-'03

See sketch of Fig. 7

$B = 542 \times 3 = 1626$ $T = 0$

$B = \frac{SI}{c} = \frac{Sd_4^3}{10.2}$ let $S = 8000$

$1626 = \frac{8000\, d_4^3}{10.2}$

$d_4^3 = \frac{1626 \times 10.2}{8000} = 2.073$

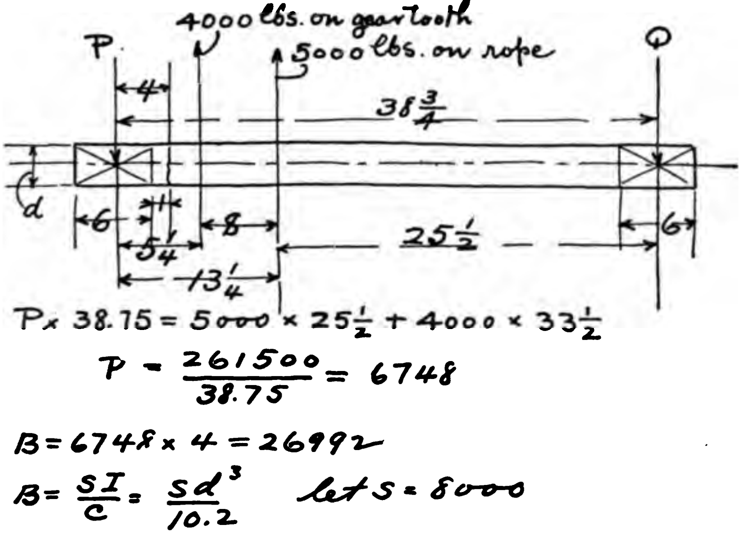
$d_4 = \sqrt[3]{2.073} = 1.27$ say $1\frac{5}{16}$

Fig. 8.

Preliminary Layout. Fig. 10. Proceeding now with the layout to scale, the detail of the parts may be worked out as completely as the scale of the drawing will permit. The work on this drawing may be of an unfinished, sketchy nature, but the measurements must be exact as far as they go, for this drawing is to serve as the reference sheet, from which all future detail is to be worked up.

In this layout may be worked out the sizes of the arms and hubs of pulleys and gears, the proportions of the drum and brake

Drum shaft May 22'03



$$P \times 38.15 = 5000 \times 25\tfrac{1}{2} + 4000 \times 33\tfrac{1}{2}$$

$$P = \frac{261500}{38.75} = 6748$$

$$B = 6748 \times 4 = 26992$$

$$B = \frac{SI}{c} = \frac{Sd^3}{10.2} \quad \text{let } S = 8000$$

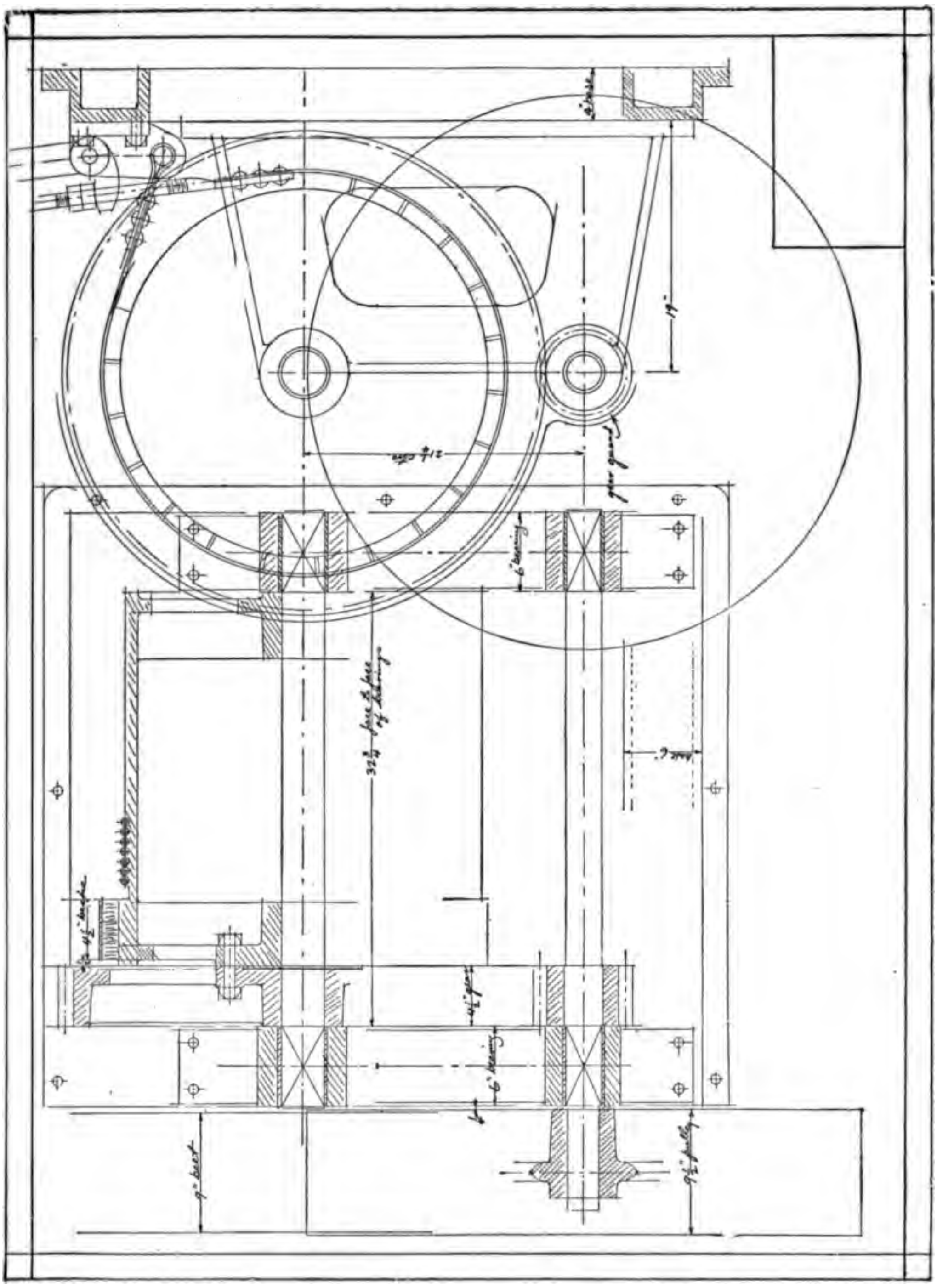
$$26992 = \frac{8000\,d^3}{10.2}$$

$$d^3 = \frac{26992 \times 10.2}{8000} = 34.415$$

$$d = \sqrt[3]{34.415} = 3.25 \quad \underline{\underline{\text{say } 3\tfrac{1}{4}}}$$

Fig. 9.

strap, and the general dimensions of the side brackets and the base. When the detail becomes too fine to work out to advantage on this drawing it may be worked out full size by a separate sketch, or left to be finished when it is regularly detailed. The preliminary layout, it should be remembered, is a service sheet only, a means of carrying along the design, and not intended for



21¼ ctrs
19"
gear guard
6" bearing
32¾ face to face of bearings
4½" brake
4½" gear
6" bearing
9" belt
9½" pulley

Fig. 10.

a finished drawing. The moment that the free use of the layout is impaired by trying to make too much of a drawing of it, its value is largely lost. A designer must have some place to try out his schemes and devices, and the layout drawing is the place to do it. This drawing may be recurred to at intervals in the progress of the design, details being filled in as they are worked out, as they may control the design of adjacent parts.

As the discussion of the design of each of the members involved in the present problem can be better taken up in connection with the detail drawing of each, it will be given there, rather than in connection with the layout, although many of the proportions thus discussed could be worked out directly from the latter.

Pulleys. Fig. 11. The analysis of the forces in the belt gives, according to the calculation of Fig. 3, a tension in the tight side of 1,059 pounds, and in the slack side 414 pounds. The difference of these, or 1,059—414=645 pounds, is transmitted to the pulley and produces the torque in the shaft. Of course in the small pulley the torque is transmitted from the motor through the pulley to the belt, but both cases are the same as far as the loading of the pulleys is concerned.

The only other force theoretically acting is the centrifugal force due to the speed of the pulley. This produces tension in the rim and arms, but for the low value of 1,300 feet per minute peripheral velocity in this case may be disregarded.

Considering the arms as beams loaded at the ends, and that one-half the whole number of arms take the load, and for convenience, figuring the size of the arms at the center of the pulley, gives the following calculation for the large pulley:

$$\frac{645}{3}\times 21=\frac{S\times I}{c}=.0393\times 2{,}500\times h^3$$

Let $S=2{,}500$
" h=breadth of oval
" $.4h$=thickness of oval

$$h^3=\frac{4{,}515}{98.25}=46$$

$$h=\sqrt[3]{46}=3.6 \text{ (say 3.5)}$$

$$.4h=.4\times 3\ 5=1.4 \text{ (say 1 7-16)}$$

This is about all the theoretical figuring necessary on this pulley. The rim is made as thin as experience judges it capable of being cast; the arms are tapered to suit the eye, thus giving ample fastening to the rim to provide against shearing off the rim

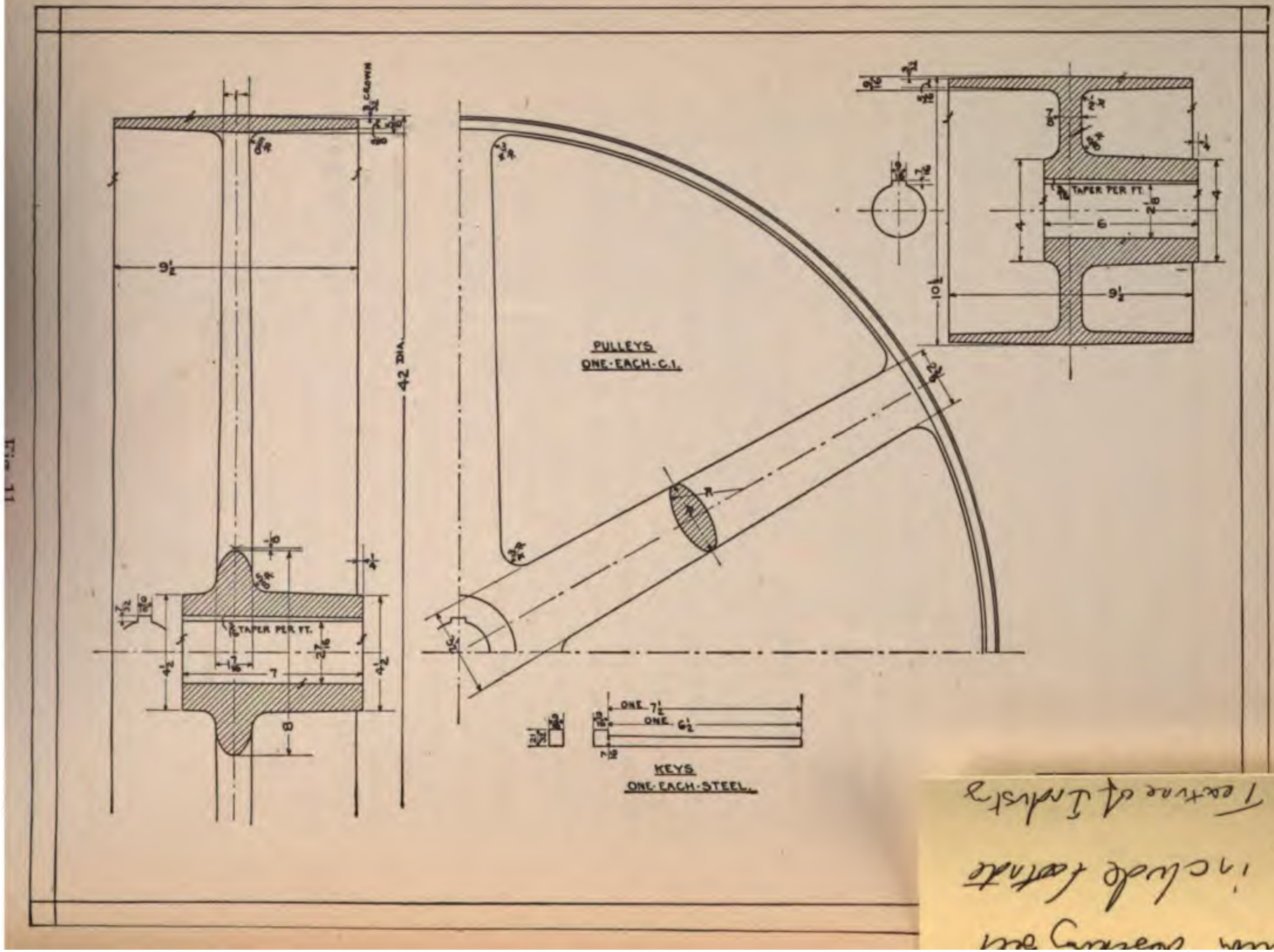


Fig. 11

[illegible]
drives, include footnote
from Texture of Industry

from the arms; generous fillets join the arms to both rim and hub; and the hub is given thickness to carry the key, and length enough to prevent tendency to rock on the shaft. Uncertain strains due to unequal cooling in the foundry mold may be set up in the arms and rim, but with careful pouring of the metal they should not be serious, and the low value chosen for the fibre stress allows considerable margin for strength.

The small pulley has the same forces to withstand as the large pulley, but on account of its small diameter there is not room enough for arms between the rim and the hub, hence it is made with a web. The web cannot be given any bending by the belt pull, the only tendency which exists in this case being a shearing where the web joins the hub. This shearing also exists throughout the web as well, but at other points farther from the center it is of less magnitude, and moreover, there is more area of metal to take it. The natural way to proportion the thickness of the web is to give it an intermediate thickness between that of the hub and rim, thus securing uniform cooling, and then figure the stress as a check. Making this value $\frac{7}{8}$ inch gives a shearing area of $\frac{7}{8}$ multiplied by the circumference of the hub, which is $3.1416 \times 4 = 12.56$. The shearing force at the hub is $\frac{645 \times 5.25}{2} = 1{,}693$ pounds. Equating the external force to the internal resistance

$$1{,}693 = \tfrac{7}{8} \times 12.56 \times S$$

$$S = \frac{1{,}693 \times 8}{7 \times 12.56} = 154 \text{ pounds per square inch (approx.).}$$

This is a very low figure, even for cast iron, hence the web is amply strong. The rim and hub are proportioned as for the large pulley.

The keys are taken from the standard list. They may be checked for shear, crushing in the hub, and crushing in the shaft, but the hubs are so long that it is at once evident without figuring that the stress would run very low in both cases.

Gears. Fig. 12. The analysis of the forces acting on the gears has been given on page 28, 4,000 pounds being taken at the pitch line. Using this same value, and choosing a T-shaped arm as a good form for a heavily loaded gear like the present one, let us consider that the rim is stiff enough to distribute the load

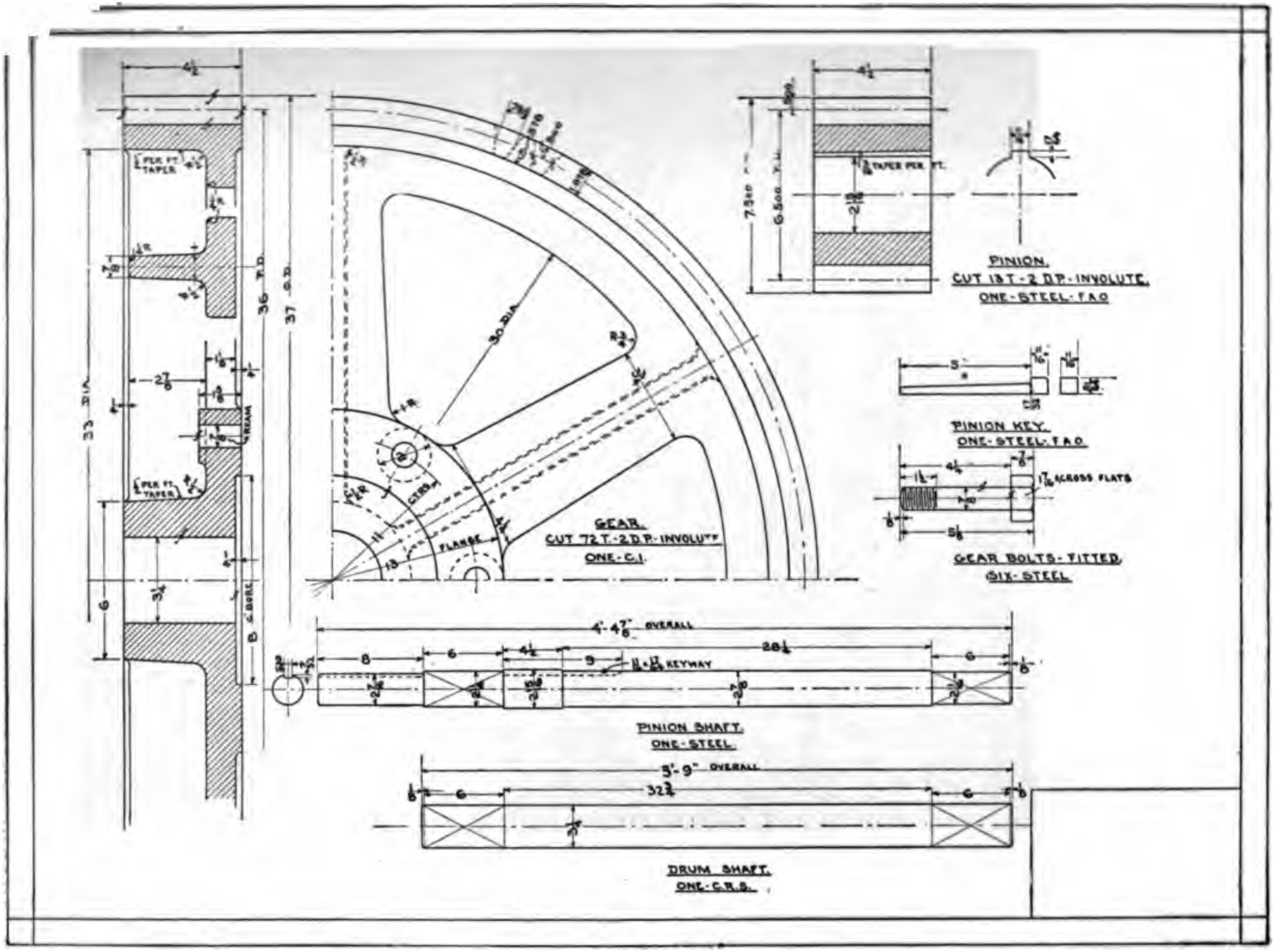

GEAR.
CUT 72 T.-2 D.P.-INVOLUTE
ONE-C.I.
30 DIA
FLANGE
33 DIA
36 P.D.
37 O.D.
PER FT. TAPER
REAM
8 C'BORE
PINION.
CUT 13 T.-2 D.P.-INVOLUTE.
ONE-STEEL-F.A.O.
7.500
6.500 P.D.
TAPER PER FT.
PINION KEY.
ONE-STEEL-F.A.O.
5"
GEAR BOLTS-FITTED.
SIX-STEEL.
ACROSS FLATS
4'-4 7/8" OVERALL
28 1/2
KEYWAY
PINION SHAFT.
ONE-STEEL.
5'-9" OVERALL
32 3/4
DRUM SHAFT.
ONE-C.R.S.

Fig. 12.

equally between all the arms, and that each acts as a beam loaded at the end with its proportion of the tooth load. Before we can determine the length of these arms, however, we must fix upon the size of the flange which is to carry the driving bolts. This is taken at 13 inches. It could be smaller if desired, but drawing the bolts in toward the center increases the load on them, and 13 inches seems reasonable until it is proved otherwise. This makes the maximum moment which can come on an arm $\frac{4{,}000 \times 11.5}{6} = 7{,}666$ inch-pounds.

Now it is evident that the base of the T arm section, which lies in the plane of rotation, is most effective for driving, and that the center leg of the T does not add much to the driving capacity of the arm, although it increases the lateral stiffness of the arm, as well as providing in casting a free flow of metal between the rim and the hub. Hence the simplest way of treating the section of the arm for strength is to consider the base of the T only, of rectangular section, breadth b, and depth h, for which the internal moment of resistance is $\frac{S \times b \times h^2.}{6}$

Also, it is simplest to assume one dimension, say the breadth, and the allowable fibre stress, and figure for the depth. Taking the breadth at 1⅛ inches, which looks about right, and the fibre stress at 2,500, and equating the external moment to the internal, we have

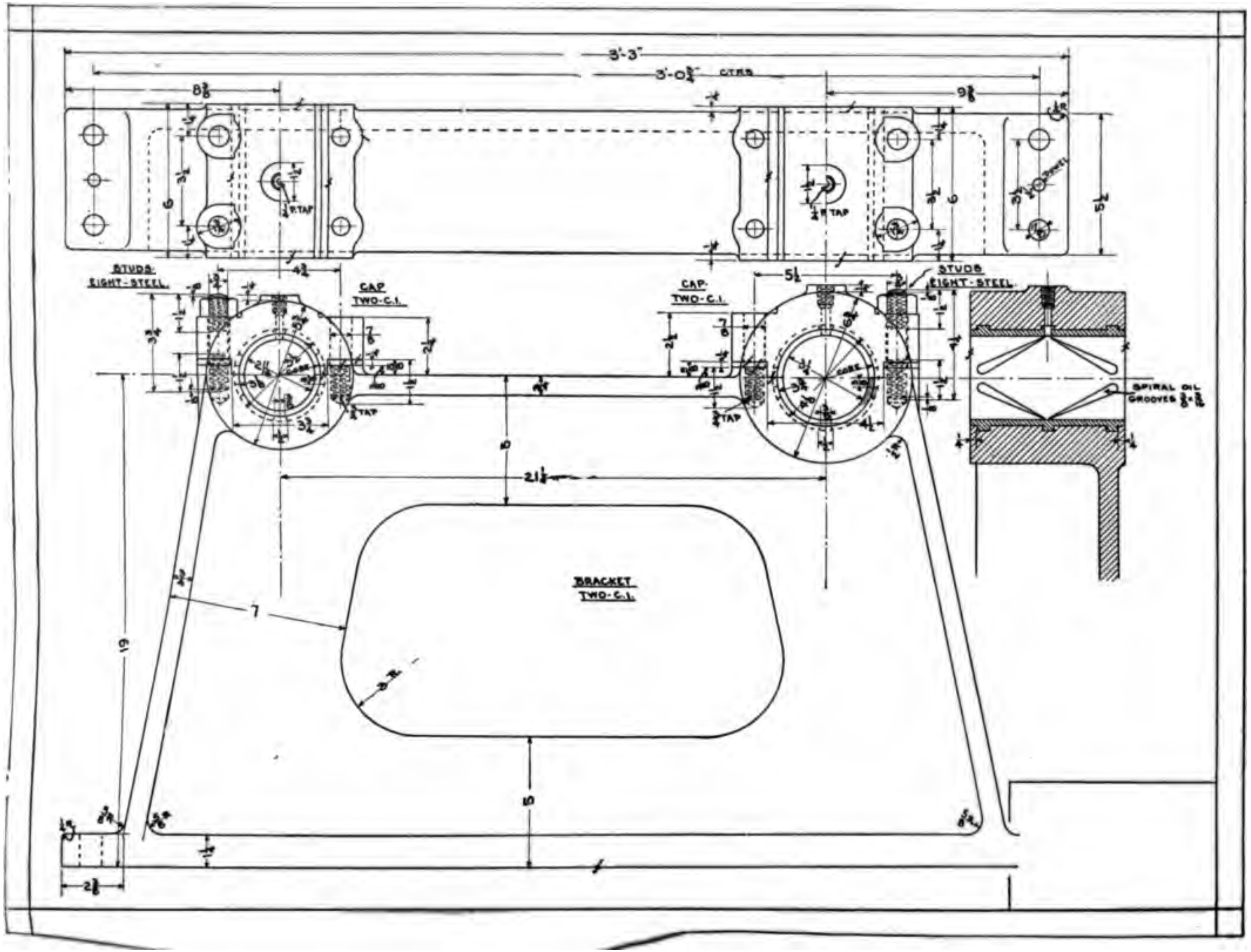
$$7{,}666 = \frac{2{,}500 \times 1.125 \times h^2}{6}$$

$$h^2 = \frac{6 \times 7{,}666}{2{,}500 \times 1.125} = 16.4$$

$$h = \sqrt{16.4} = 4.05 \text{ (say } 4\tfrac{1}{4}\text{)}$$

Drawing in this size, and tapering the arm to the rim as in the case of the pulleys, making the depth of the rim according to the suggested proportions given in Part II, "Gears," giving the center leg of the T a thickness of ⅞ inch tapering to 1 inch, and heavily filleting the arms to the rim and center flange, we have a fairly well proportioned gear.

The next thing to determine is the size of the driving bolts. The circle upon which their centers lie may be 11 inches in diam-


3'-3"
3'-0¾" CTRS
8⅜
9⅜
5½
4½
STUDS EIGHT-STEEL
CAP TWO-C.I.
CORE
TAP
SPIRAL OIL GROOVES ⅜ × 3⁄16
21⅛
BRACKET TWO-C.I.
7
19
5
2⅛
DOWEL

eter, and there will naturally be six bolts, one between each arm. These bolts are in pure shear, and the material of which they are to be made ought to be good for at least 8,000 pounds per square inch fibre stress. The force acting at the circumference of an 11-inch circle would be $\frac{4{,}000\times 18}{5.5}=13{,}091$ pounds.

Equating the load on each bolt to the resisting shear gives

$$\frac{13{,}091}{6}=8{,}000\times A=\frac{8{,}000\times 3.1416\times d^2}{4}$$

Let A=area resisting shear.
Let d=dia. of bolt.
Then $A=\frac{\pi d^2}{4}$

$$d^2=\frac{4\times 13{,}091}{6\times 8{,}000\times 3.1416}=.35$$

$d=\sqrt{.35}$ (say .6) $\frac{5}{8}$-inch bolts would do.

But $\frac{5}{8}$-inch bolts are pretty small to use in connection with such heavy machinery. They look out of proportion to the adjacent parts. Hence $\frac{7}{8}$-inch bolts have been substituted as being better suited to the place in spite of the fact that theoretically they are larger than necessary. The extra cost is a small matter. These bolts may crush in the flange as well as shear off, but as there is an area of $\frac{7}{8}\times 1\frac{5}{8}=1.422$ square inches to take $\frac{13{,}091}{6}=2{,}182$ pounds, the pressure per square inch of projected area is only $\frac{2{,}182}{1.422}=1{,}534$ pounds, which is very low.

This gear needs no key to the shaft because all the power comes down the arms and passes off to the drum through the bolts, thus putting no torsional stress in the shaft. The face of the flange is counterbored so as to center the gear upon the drum, without relying upon the fit of the gear upon the shaft to do this.

The pinion is solid and needs no discussion for its design.

Brackets and Caps. Fig. 13. As the size of the drum shaft was determined by considering the rope wound close up to the brake, thus giving in combination with the load on the gear tooth the maximum reaction at the bearing as 6,748 pounds, the cap and bolts should be designed to carry the same load.

For a bearing but 6 inches long, two bolts are sufficient under ordinary conditions and might perhaps do for this case. The load is pretty heavy, however, and it is deemed wise to provide four bolts, thus securing extra rigidity, and permitting the use of bolts of comparatively small size. If the load were distributed equally over all the bolts each would take one-fourth of the whole load, but it is not usually safe to figure them on this basis, because it is difficult to guarantee that each bolt will receive its exact share of stress. Assuming that the two bolts on one side take $\frac{2}{3}$ the whole load instead of $\frac{1}{2}$, which provides for this uncertain extra stress, each bolt must take care of $\frac{1}{3}$ of 6,748, or 2,249, pounds. Allowing 8,000 pounds per square inch fibre stress calls for an area at the root of the thread of $\frac{2,249}{8,000} = .281$ square inch. Consulting a table of bolts we find that the next standard size of bolt greater than this is $\frac{3}{4}$, which gives an area of .302 square inch.

Choosing this size as satisfactory, the bolts should be located as close to the shaft as will permit the hole to be drilled and tapped without breaking out. A center distance of $5\frac{1}{2}$ inches accomplishes this result. The distance between centers in the other direction is somewhat arbitrary, although the theoretical distance between the bolt and the end of the bearing to give equal bending moment at the center of the cap and at the line of the bolts is about $\frac{5}{24}$ of the length, or $\frac{5}{24}$ of $6 = 1\frac{1}{4}$ inches. This proportion answers well for the present case, although for long caps it brings the bolts too far in to look well.

The thickness of the cap may be determined by assuming it to be a beam supported at the bolts and loaded at the middle. This is not strictly true, for the load is distributed over at least a portion of the shaft diameter; moreover, the bolts to some extent make the beam fixed at the ends. It being impossible to determine the exact nature of the loading, we may take it as stated, supported at the ends and loaded in the middle, and allow a higher fibre stress than usual, say 3,500. The longitudinal section at the middle of the cap is rectangular, of breadth 6 inches, and depth unknown, say h. The equation of moments is

$$\frac{W \times l}{4} = \frac{S \times I}{c} = \frac{S \times b \times h^2}{6}$$

$$\frac{6,748 \times 5.5}{4} = \frac{3,500 \times 6 \times h^2}{6}$$

$$h^2 = \frac{64 \times 6,748 \times 5.5}{4 \times 3,500 \times 6} = 2.65$$

$h = \sqrt{2.65}$ will probably answer)

For the other bearing next to the pinion, the load on the tooth acts downward, and the resultant pull of the belt is nearly horizontal, hence the cap and bolts must stand but little load, and calculation would give minute values. In a case like this it is well to make the size the same as for the larger bearing, unless the construction becomes very clumsy thereby. This saves changing drills and taps in making the holes, and preserves the symmetry of the bracket. The ¾-inch bolts are good proportion for the smaller bearing, hence that size will be maintained throughout.

The body of the bracket is conveniently made with the web at the side and horizontal ribs extending to the outside. The load due to the rope is carried directly down the side ribs and web into the bottom flanges and to the bolts. The analysis of the forces on these bolts is shown in Fig. 14. It is evident from the figure that the resultant belt pull tends to hold the bracket down, while the load on the rope tends to pull it up, the point about which it tends to rotate being the corner furthest from the drum. It is also evident that the bolts nearest this corner can have little effect on the holding down, because their leverage is so small about the corner, hence we shall assume that the pair of bolts at the right-hand end of the bracket takes all the load. The belt pull, being horizontal, tends to slide the bracket along the base, but this tendency is small, and at any rate is easily taken care of by the two dowel pins, which are thus put in shear.

The load on the bolts being 4,954 pounds, a heavy bending moment is thrown on the flange of the bracket, tending to break it off at the root of the fillet. The distance to the root of the fillet is ¾ inch; the section tending to break is rectangular, of breadth 5½ inches, and unknown depth h. The equation of moments is

$$\mathrm{W} \times l = \frac{\mathrm{S} \times \mathrm{I}}{c} = \frac{\mathrm{S} \times b \times h^2}{6}$$

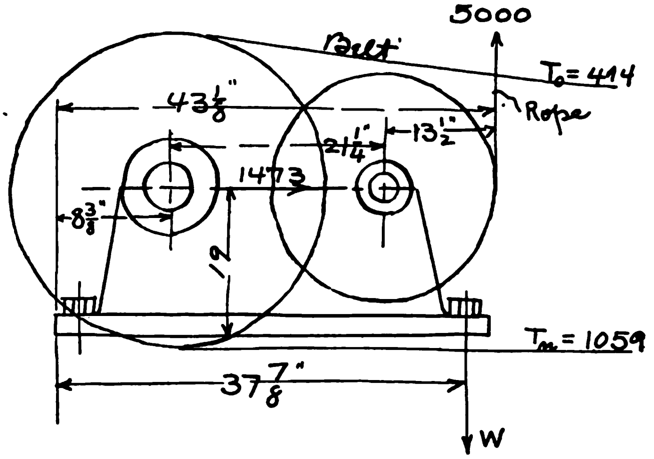
$$\frac{4{,}954 \times 3}{4} = \frac{2{,}500 \times 5.5 \times h^2}{6}$$

$$h^2 = \frac{6 \times 4{,}954 \times 3}{4 \times 2{,}500 \times 5.5} = 1.62$$

$$h = \sqrt{1.62} = 1.3 \text{ (say } 1\tfrac{1}{4}\text{).}$$

The thickness of the web and ribs of this bracket is hardly capable of calculation. The figure ¾ inch has been chosen in proportion to the size of the large drum bearing, giving ample stiffness and rigidity, and permitting uniform flow and cooling of the metal in the mold. The opening in the center is made merely to save material, as in that part little stress would exist, the two sides

Bracket base bolts May 25-1903



$$5000 \times 43\tfrac{1}{8} = 37\tfrac{7}{8} \times W + 1473 \times 19$$

$$W = \frac{5000 \times 43.125 - 1473 \times 19}{37.875}$$

W = 4954 lbs on two bolts

$\frac{4954}{2} = 2477$ lbs per bolt.

$\frac{2477}{8000} = .31$ sq. in. area at 8000 lb. stress.

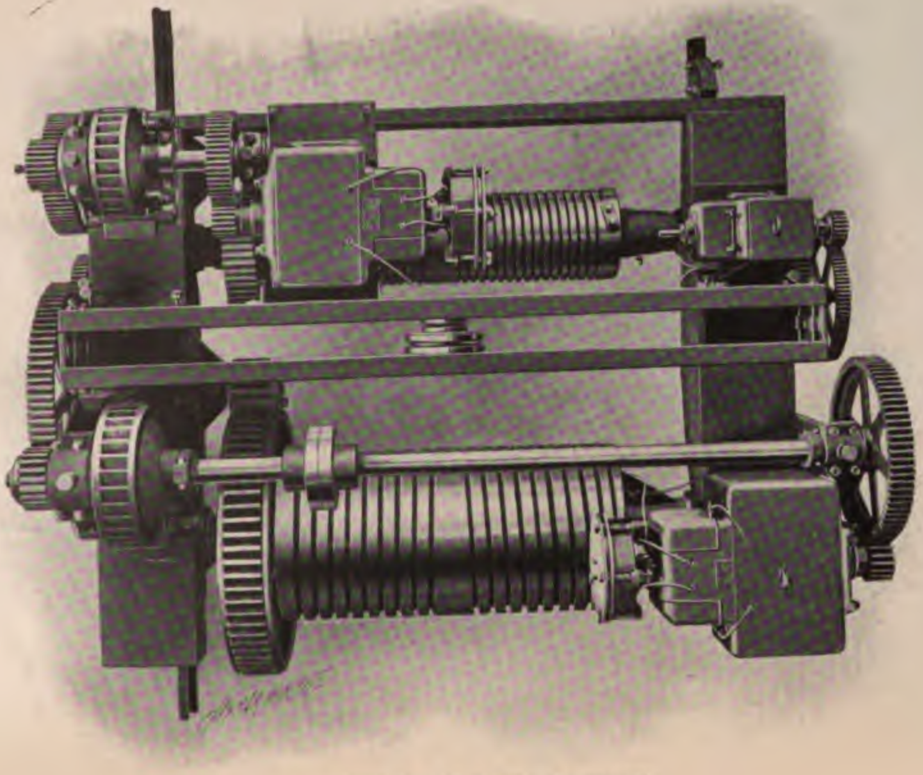
Area at root of thread for a $\frac{3}{4}$ bolt is .28

Hence $\frac{3}{4}$ bolts will answer.

Fig. 14.

carrying the load down to the base bolts, and the top serving as a tie between the bearings.

This bracket might be made with the web in the center of the bearings instead of at the side, in which case the expense of the



TROLLEY OF 15 TONS CAPACITY.
The Case M'f'g Co.

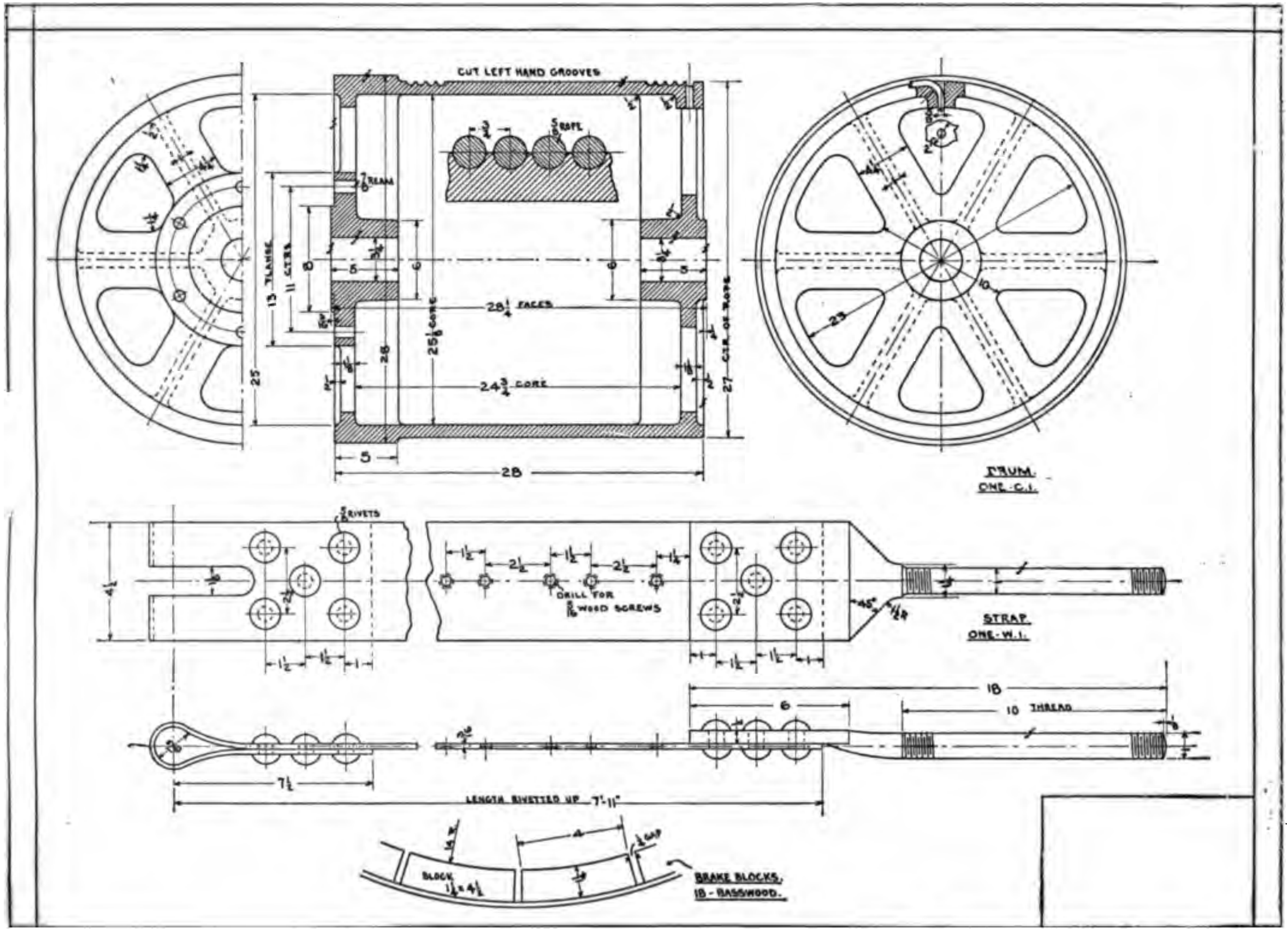
pattern would be slightly greater. It could also be made of closed box form, but would in that case probably weigh more than as shown.

Drum and Brake. Fig. 15. The analysis of the forces acting on the drum is simple, but its theoretical design is more complicated. It is evident that the drum acts as a beam of hollow circular cross section, and that its worst case of loading is when the rope is at or near the middle of the drum length. At the same time the metal of this circular cross section is in a state of torsion between the free end of the rope and the driving gear, due to the load on the gear tooth and the reaction of the rope. Also the wrapping of the rope around the drum tends to crush the metal of the section beneath it, the maximum effect of this action being near the free end of the rope where its tension has not been reduced by friction on the drum surface.

Now the "mechanics" to solve the problem of these three combined actions is rather complicated. It can be at least approximately solved, however, for it satisfies fairly well the case of combined compression and shear. But on a further study of this particular case, it is seen at once that the diameter of the drum is relatively large with respect to its length, which means that the thickness of the metal may be very small and yet give a large resisting area, or value of "I," both in direct bending as well as torsion; also it is so short that the external bending moment will be small. The practical condition now comes in, that the drum can be safely cast only when the thickness of the metal is at a minimum limit, for the core may be out of round, not set centrally, or by some other variation produce thin spots or even develop holes reaching out into the rope groove, discovered only when the latter is turned in the lathe.

Hence it seems reasonable and safe in this case to make the thickness of the drum depend simply upon the crushing caused by the wrapping of the rope around it, and we shall take the coil nearest the free end of the rope, assuming that it carries the full load of 5,000 pounds throughout one complete wrap around the drum.

The area resisting the crushing action may be considered to be that of the cross section of a ring, of width equal to the pitch


CUT LEFT HAND GROOVES
5/8 ROPE
7/8 REAM
13 FLANGE
11 CTRS
28 1/4 FACES
25 5/8 CORE
24 3/4 CORE
27 CTR OF ROPE
28
25
5
DRUM.
ONE-C.I.
5/8 RIVETS
DRILL FOR 3/16 WOOD SCREWS
45°
STRAP.
ONE-W.I.
18
10 THREAD
6
7 1/2
LENGTH RIVETTED UP 7'-11"
BLOCK 1 1/2 x 4 1/2
1/8 GAP
4
BRAKE BLOCKS.
18 - BASSWOOD.

of the groove. Assuming that $\frac{5}{8}$ inch is the least thickness which can be safely allowed under the groove for casting purposes, let us figure the crushing fibre stress to see if this is sufficiently strong. Disregarding the small amount of metal existing above the bottom of the groove, this gives the area to resist the crushing $\frac{5}{8} \times \frac{3}{4} \times \frac{15}{32}$, or .47 inch. Since there are two of these sections and the rope acts on both sides, the equation of forces is:

$$5{,}000 \times 2 = S \times .47 \times 2$$

$$S = \frac{5{,}000 \times 2}{.47 \times 2} = 1{,}062 \text{ pounds per square inch.}$$

This, for cast iron, is very low, and allows plenty of margin for the extra bending and torsional stress, which for such a considerable thickness would be slight.

The above case indicates a method of reasoning much used in designing machinery, which while following out the specified routine of thought as previously given in these pages, stops short of elaborate and minute theoretical calculation when such is obviously unnecessary. If a drum of great length were to be designed, and of small diameter, the same method of reasoning would deduce the fact that the design should be based on the bending and the torsional moments, the thickness in such a case being so great to withstand these that the intensity of the crushing due to wrap of the rope becomes of inappreciable value.

The remaining points of design of the drum are determined from practical considerations and judgment of appearance. The ribs behind the arms are put in to give lateral stiffness and guard against endwise collapse. The arms are subject to the same bending as those of the gear, but as they are equally heavy it is not necessary to calculate them. The flange at the driving end is of course matched to that already designed for the gear. The rope is intended to be brought through the right-hand end with an easy bend and the standard form of button wedged on to prevent its pulling through.

This drum would probably be cast with its axis vertical, and the driving flange down to secure sound metal at that point. Heavy risers would be left at the other end to secure soundness where the rope is fastened. Drums are often cast with the axis horizontal, but the vertical method is more certain to produce a sound casting. The grooves should be turned from the solid metal, partly because it is a difficult matter to cast them, but principally because the rope should run on as smooth surface as possible to avoid undue wear. On drums which carry chain instead of wire rope the grooves are sometimes cast with success, although even in this case the turned groove is generally preferable.

The brake consists of a wrought-iron band to which are fastened wooden blocks, the iron band giving the requisite strength while the blocks give frictional grip on the drum surface and can be easily replaced when worn. As in the designing of a belt the object in view is the grip on the pulley surface by the leather to enable power to be transmitted from the belt to the pulley, so in the case of the brake if we put the proper tension in the strap it can be made to grip the brake drum so tightly that motion between it and the drum cannot occur. The latter case is really the reverse of the first, if the driven pulley be considered, but is identical with the case of the driving pulley, in which the power is transmitted from the pulley to the belt. Of course in the case of the brake no power is transmitted, as when the brake holds no motion occurs, but the principle of the relative tensions in the strap is the same as for the belt.

Since the brake drum surface is 28 inches in diameter, the load at that surface which the brake must hold is

$$P = \frac{5{,}000 \times 27}{14 \times 2} = 4{,}821 \text{ pounds.}$$

We have then the following calculation corresponding exactly to that of the belt given in Fig. 3.

$$\log.\ \frac{T_n}{T_o} = 2.729 \times \mu \times n \qquad \begin{array}{l} \text{Let } \mu = .25 \\ \text{“} \quad n = .75 \end{array}$$

$$T_n - T_o = P = 4{,}821$$

$$\log.\ \frac{T_n}{T_o} = 2.729 \times .25 \times .75 = 0.512 \ \left(\text{for which the natural number is } 3.25\right).$$

$$\text{Then } \frac{T_n}{T_o} = 3.25 \qquad T_o = \frac{T_n}{3.25}$$

$$T_n - T_o = 4{,}821 \qquad T_n - \frac{T_n}{3.25} = \frac{2.25 \times T_n}{3.25} = 4{,}821$$

$$T_n = \frac{4{,}821 \times 3.25}{2.25} = 6{,}963 \text{ pounds (say 7,000)}$$

$$T_o = 6{,}963 - 4{,}821 = 2{,}142 \text{ pounds (say 2,200)}$$

The tight end of the strap must then be capable of carrying a load of 7,000 pounds, and since the width has already been taken at $4\frac{1}{2}$ inches, the problem is to find the necessary thickness. Equating the external load to the internal resistance we have

$$7{,}000 = A \times S \qquad \text{Let } t = \text{thickness}$$

$$\text{`` } S = \text{fibre stress} = 12{,}000$$

$$7{,}000 = 4.5 \times t \times 12{,}000$$

$$t = \frac{7{,}000}{4.5 \times 12.000} = .13 \text{ inch}$$

This, however, can be but a preliminary figure, for the riveting of the strap will take out some of the effective area, and the thickness will have to be increased to allow for this. Suppose on the basis of this figure we assume the thickness at a slightly increased value, say $\frac{3}{16}$ inch, and proceed to calculate the rivets.

A group of five rivets will work in well for this case, which gives $\frac{7{,}000}{5} = 1{,}400$ pounds per rivet. A safe shearing fibre stress is 6,000, hence the area necessary per rivet is $\frac{1{,}400}{6{,}000} = .23$ square inch. This comes nearest to the area $\frac{9}{16}$ diameter, but for the sake of using the more general size of rivet ($\frac{5}{8}$ inch) the latter is chosen, for which the area is .30.

We must now try these rivets in a $\frac{3}{16}$-inch plate for their safe bearing value. The projected area of a $\frac{5}{8}$-inch hole in a $\frac{3}{16}$-inch plate is $\frac{5}{8} \times \frac{3}{16} = .117$ square inch. $\frac{1{,}400}{.117} = 11{,}965$ (15,000 would be safe)

Taking out two $\frac{5}{8}$-inch rivets from the full width of $4\frac{1}{2}$ inches leaves $4\frac{1}{2} - (2 \times \frac{5}{8}) = 3.25$, and makes the net area of strap to take stress $3.25 \times \frac{3}{16} = .61$ square inches. Re-calculating the fibre stress for this area gives

$$7{,}000 = .61 \times S$$

$$S = \frac{7{,}000}{.61} = 11{,}475$$ (which approximates the previous value of 12,000):

The slack end of the strap has to take but 2,200 pounds, hence a different calculation might be made for this end giving smaller rivets; but as it is impractical to change the thickness of the strap to meet this reduced load, it is well to maintain the same proportion of joint as at the tight end. The spacing of the rivets in both

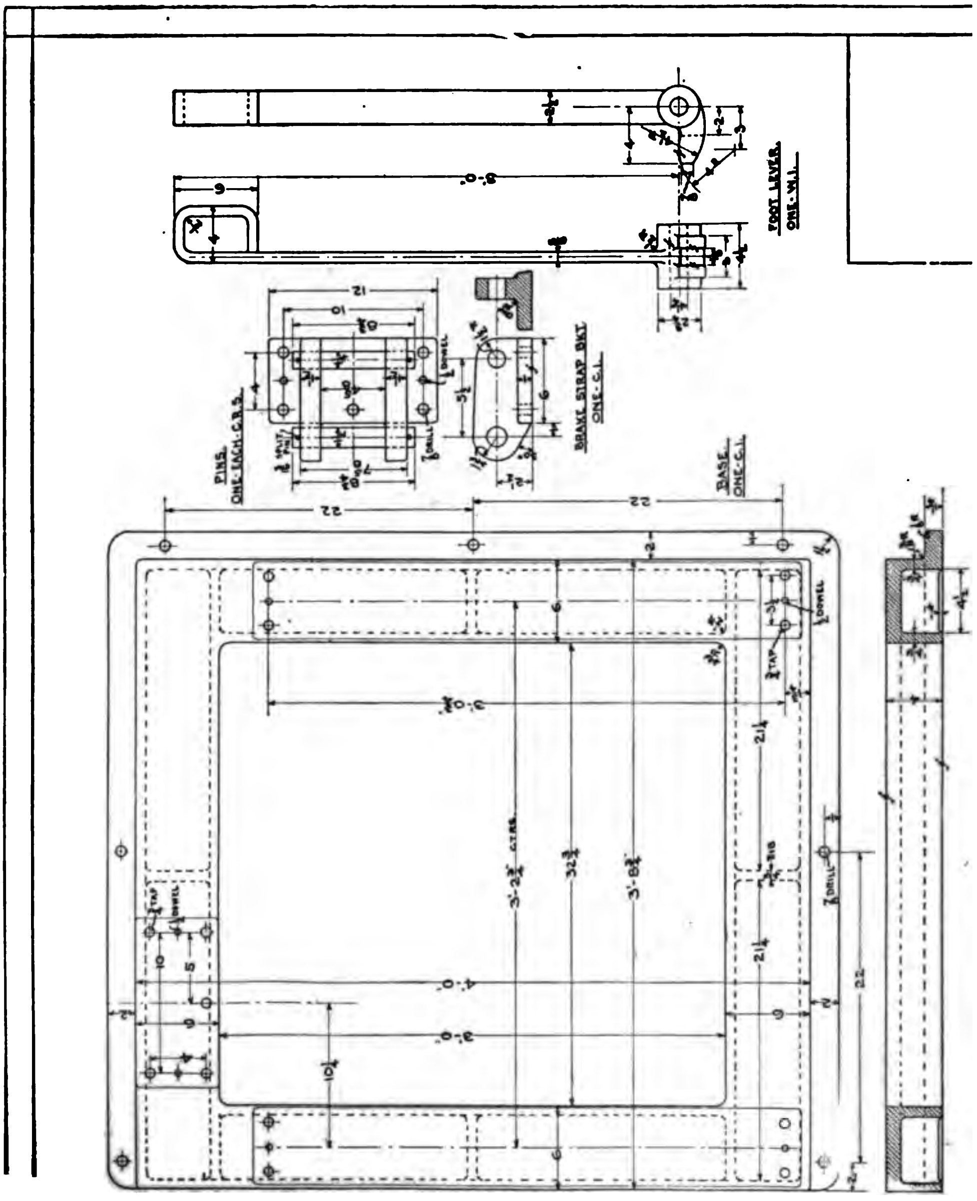

FOOT LEVER. ONE-W.I.
PINS. ONE-EACH-C.R.S.
BRAKE STRAP BKT. ONE-C.I.
BASE. ONE-C.I.

Fig. 16.

cases follows the ordinary rule allowing at least three times the diameter of the rivet as center distance, and one-half this value to the edge of the plate.

The threaded end of the forging on the strap also has to carry tho load of 2,200 pounds, for which a size smaller than 1 inch would suffice. It is natural, however, for the sake of general proportion to make the bolt as strong as the strap, and a 1-inch bolt gives an area of .52 square inch, nearly equalling the value of .61 net area of strap noted above.

Base, Brake-Strap Bracket and Foot Lever. Fig 16. The base cannot be definitely calculated, and can best be proportioned by judgment. It must not distort, twist, or spring in any way to throw the shafts out of line. The area in contact with the foundation upon which it rests must be ample to carry the weight of the whole machine with a low unit pressure. Although the form shown is perfectly practicable to cast and machine, and is simple and rigid, yet it is questionable if a bolted-up construction, say of four pieces, might not be equally rigid and yet involve greater facility of production in both the foundry and machine shop on account of the reduced sizes of parts to be handled. This is a question which depends on the equipment and methods of the individual shop, and is an illustration of the practical control of design by manufacturing conditions.

The brake-strap bracket and foot lever, also shown in this figure, are examples of machine parts which are quite definitely loaded, and the designing of which is a simple matter. Further discussion of their design is not made, the student being given opportunity for some original thought in determining the forces and moments that control their design.

Gear Guard and Brake-Relief Spring. In exposed machinery of this character it is desirable to cover over the gears with a guard to prevent anything accidentally dropping between the teeth and perhaps wrecking the whole machine. This guard is not shown, as it involves little of an engineering nature to interest the student. It could readily be made of sheet metal or light boiler plate, bent to follow the contour of the gears and fastened to the top flange of the main bracket.

If the brake be not automatically supported at its top it will lie with considerable pressure, due to its own weight, on the brake surface when it is supposed to be free from it, and by the friction thereby created will produce a heavy drag and waste of power. A spring connection fastened to an overhead beam is a simple way of accomplishing the desired result. A flat supporting strap carried out from the gear guard, having some degree of spring in it, is a neater method of solving the problem. The spring should be just strong enough to counterbalance the weight of the strap and yet not resist to an appreciable degree the force applied to throw the brake on.

GENERAL DRAWING.

The last step in the process of design of a machine is the making of the assembled or general drawing. This should be built up piece by piece from the detail drawings, thereby serving as a last check on the parts going together. This drawing may be a cross section or an outside view. In any case it is not wise to try to show too much of the inside construction by dotted lines, for if this be attempted, the drawing soon loses its character of clearness, and becomes practically useless. A general drawing should clearly **hint at, but not specify,** detailed design. It is just as valuable a part of the design as the detail drawing, but it cannot be made to answer for both with any degree of success. A good general drawing has plenty of views, and an abundance of cross sections, but few dotted lines.

The general drawing of the machine under consideration is left for the student to work up from the complete details shown. It would look something like the preliminary layout of Fig. 10, if the same were carefully carried out to finished form. A plain outside view would probably be more satisfactory in this case than a cross section, as the latter would show little more of value than the former. The functions which the general drawing may serve are many and varied. Its principal usefulness is, perhaps, in showing to the workman how the various parts go together, enabling him to sort out readily the finished detail parts and assemble them, finally producing the complete structure. Otherwise the making of a machine, even with the parts all at hand, would be like the putting together of the many parts of an intricate puzzle, and much time would be wasted in trying to make the several parts fit, with perhaps never complete success in giving each its absolutely correct location.

The general drawing also gives valuable information as to the total space occupied by the completed machine, enabling its location in a crowded manufacturing plant to be planned for, its connection to the main driving element arranged, and its convenience of operation studied.

In some classes of work it is a convenient practice to letter each part on the general drawing, and to note the same letters on the specification or order sheet, thus enabling the whole machine to be ordered from the general drawings. This is a very excellent service performed by the general drawing in certain lines of work, but for such a purpose the drawing is quite inapplicable in others.

Merely as a basis for judgment of design, the general drawing fulfils an important function in any class of work, for it approaches the nearest possible to the actual appearance that the machine will have when finished. A good general drawing is, for critical purposes, of as much value to the expert eye of the mechanical engineer as the elaborate and colored sketch of the architect is to the house builder or landscape designer.

From the above it is readily understood that the general drawing, although a mere putting together of parts in illustration, is yet of great assistance in producing finished and exact machine design.

GENERAL COMMENTS ON PRECEDING PROBLEM.

After following through the detail of work as given in the preceding pages, it is worth while to stop for a moment and take a brief survey or review of the subject as illustrated therein.

If the text be carefully studied it will be seen that in every part to be designed the same routine method has been followed, regardless of the final outcome. In some cases it may seem a roundabout procedure to follow a train of thought that finally ends in a design apparently based on purely practical judgment, the theory having had but very little if any influence. The question at once arises—Why not use the empirical rule or formula in the first place? Why not make a good guess at once? Why not save all the time and energy devoted to a careful analysis and theory, if we are finally to throw them away and not base our design on them?

The principle to be noted in this connection is, that it is just as fatal to good design to rely upon bare experience and upon judgment alone, as it is to construct solely according to what pure theory tells us. There are many things in the operation of machinery that are totally inexplicable from the purely practical point of view, and will forever remain so until we analyze them and theorize on them. Many good things in machinery have been the result of what might be called "reversed" machine design. When a new machine is started, it frequently, or we might almost say always, fails to do its work just as it is expected to do it. This is because some little point of design is bad, owing to the inability of drawings, however good they may be, to show all that the machine itself in bodily form and in motion shows.

Now, if our analysis and theory have been good in the designing process, it is almost sure that we can very readily analyze and theorize on the trouble that exists when the machine is finished, can detect the weakness, and can correct it with comparatively small change in the general design. This is "reversed" machine design.

If, on the contrary, we have based our design purely on guesswork, allowing our fancy full and free play to work out the details without further basis, we may consider ourselves lucky if the machine runs at all. This, however, is not the worst of the situation. If the machine does actually operate, even as well as it might reasonably be expected to, but still has the usual difficulty of some little kink or hitch that was not expected, then, as a result of the method upon which the whole thing has been constructed, we have no definite plan of action to proceed upon. We must try first this, then that scheme to obviate the trouble. We may be fortunate enough to "strike it" the first time; we may never strike it. It is doubtful if the machine ever can be made to work at highest efficiency; and if fairly good results be finally obtained we never know the reason why, and have nothing on which to base any future action or design.

This haphazard process is not machine design at all, either in name or in result.

As has previously been stated in these pages, there is no such thing as too much analysis or theory in the designing of machinery. Even if we carefully analyze, theorize with rigorous exactness, and then practically modify our construction to such a point that the original theoretical shape is almost or entirely lost, the apparently roundabout process is not in vain, for we are in perfect control of our design. We know exactly what it has to take in the way of forces, blows and vibrations. We know what its ideal shape should be. We know where we can practically modify its form without weakening it excessively or adding excess of material. In other words we know all about it, and therefore know exactly what we can do with it; and whether it follows in its shape the outline that pure theory gives it or some other outline, it is nevertheless well designed.

"Reversed" machine design, as described above, based on observation and experiment with regard to machines already in operation, is just as impossible without exact analysis and theory as is original design based merely on mechanical ideas in the abstract. The method once learned and made a habit of mind will produce results with equal facility in either case, and results are what the mechanical world is seeking.

Another point worth noting in the progress of the problem as given is the absolute necessity of possessing some knowlege of Mechanics. The more of this subject the designer can have at his finger ends, the more ready and successful will he be in all problems of Machine Design. However, the principles of forces and moments clearly understood, and the application of the same in the all-important subject, "Strength of Beams," constitute a fund of information that will give a splendid start and a good working basis for simple designs. It should always be remembered that a complicated design is little more than a combination of simple designs, and if one has the ability to dissect and analyze what seems at first like a bewildering maze of parts, complication is speedily changed to simplicity.

Common sense goes a long way in good designing. There is nothing mysterious about the process If the beginner will only avoid doing things that are foolish and ridiculous on their very face, if he will exercise the same judgment that he uses in the daily affairs of his life and will mix in something of mechanics and mechanical method, he will be on the direct road to success in the art.

Good drawing is an essential element of good design, and it is especially urged that the sketches and drawings as reproduced in the preceding text be studied with this in mind. By a good drawing is meant not a showy piece of work, finely shaded or artistically lettered, but an exact layout, definite and measurable, correctly dimensioned if in detail, and meaning exactly what it says. Machine design is an exact science, and the designer cannot shirk responsibility by permitting his work to be shiftless and loose. If he cannot delineate clearly and in definite form what he determines in his mind the structure should be, then it is purely good luck if he achieves success, and it may safely be asserted that the success is due to some subsequent care and finished design added to his feeble effort, rather than to any expertness of his own. Such success is of a very doubtful nature, and if not bordering on financial loss it is at least secured only at a low working efficiency.

As examples of good drawings the plates shown are not claimed to be anything extraordinary, but it will be noted that they are clean-cut and definite, and that even the sketches are unmistakable as to that which they are intended to illustrate. The information as to the design is all there; nothing is left to the imagination.

Classification of Machinery. It is intended to be made clear in all that has preceded, that the same method of attack and procedure may be applied to the designing of machinery, whatever may be the class or kind. This is a fundamental principle. When it is logically carried out, however, it produces very different results, as is evidenced by the characteristics of style peculiar to each of the classes of machinery to one or another of which all machines belong.

For example, an engine lathe has a style similar to a drill press, or a boring mill, or a screw machine, or a milling machine. It is very different, however, from the style of a steam engine, or a pump, or an air compressor, or a locomotive; it is still more different from the style of a rolling mill, or a link belt conveyor, or a coal crusher, or a stamp mill.

These classes of machinery are so distinctly marked that the novice is easily able to perceive that there is some controlling influence in each which marks its peculiar style. He should at the same time see that the very analysis that has been so strongly insisted upon in these pages is the direct cause of the marked characteristic in design. Each class of machinery must satisfy certain exacting conditions different from those of any other, and it is the careful study of these conditions, as fundamentally enforced, which leads to the strictly logical design.

A few of the most common classes are enumerated below, and their prominent features noted. It is hoped that a study of them will familiarize the student in a general way with the requirements of each, and serve as a guide to a more comprehensive study of their detail design than is possible in these pages.

Machine Tools. Examples:—lathe, planer, milling machine, drill press, screw machine, boring mill, grinding machine, etc., etc.

The machines of this class are all utilized for the finishing of metal surfaces. They are really at the root of the production of machinery of all other classes. Accuracy is their prime characteristic—accuracy of construction, accuracy of operation, accuracy of adjustment. Any inaccuracy that exists primarily in a machine tool is reproduced in every piece upon which it produces a finished surface; and since the mere act of finishing a surface upon anything implies that a rough and inaccurate surface will not answer, the tool then fails of its purpose if it cannot produce a true surface: it does not accomplish that for which it was designed.

The effect that this element of accuracy has upon the design of a machine tool is to require long bearings, convenient and exact methods of adjustment, stiffness, excess of material to absorb vibration, special shapes to facilitate application of jigs, fixtures, and exact manufacturing devices insuring interchangeability of parts, dust guards, and automatic lubrication.

Machine tools are essentially machines of maximum output, and depend for their success, not only upon their accuracy as noted, but also upon their ability to do the greatest amount of work per square foot of space occupied, with the least amount of manual labor and attention on the part of the operator. This is especially true of automatic machinery, which perhaps might be classed by itself in this respect, but which is nevertheless included under the broad term of a machine for producing finished surfaces, being merely the highest and most refined form of same. For machines of this class the designer has to study every detail with the most minute attention, packing away the operating parts into the smallest space and yet providing ready means for access, removal, and repair. Clearances that would be too little for other kinds of machinery are permitted and provided for; material of high grade, strength, and wearing quality, though expensive in first cost, and requiring the most expert skill to finish and to fit into place, must be used in order to keep the machine compact and yet of large capacity, to make it reasonably light in weight and yet amply strong.

Another point which has a great influence on the design of a machine tool is that we can never tell in advance just what it will have to stand in work, for the variation in the material that it finishes, the uncertain skill of the operator who runs it, the crowding to its limit of capacity and even beyond in times of press of business, and the many other stresses that may suddenly and without warning be thrown upon it, must all be thought of and provided for.

The points above mentioned are but a few of those which the designer of machine tools has to meet, and are presented merely as illustrations to show the special skill required in this class of machinery. It is readily seen that while the machine tool designer has great latitude in choice of material and in expenditure of money for refinement of structure—perhaps greater latitude than in any other class, yet he is held down as in no other to the final productive results, a small percentage of failure entirely throwing out the machine as a marketable product.

The style and external appearance of machine tools have a character of their own resulting from this extreme detailed care in design. Corners and fillets are carefully rounded; surfaces and intersections are definitely made; in short, the mechanical beauty of a machine tool is seen only from a near view and close inspection, and it is to this end that the design is constantly directed Appearance is a large factor in the sale of a fine tool, and the prestige of the American trade abroad in this respect is very noticeable.

Motive-Power Machinery. Examples:—Steam engine, gas engine, air compressor, steam pump, hydraulic machinery, etc., etc.

The element of heat enters into the design of all machinery in this class. The natural agents, air, gas, and water, in their various forms, are taken into the machine in the most efficient form in which it is possible to obtain them, are robbed of their energy to provide power, and are discharged in a form as weak and inert as the efficiency of the machine will determine.

In contrast to the class of machinery just studied, it should be noted that these machines do not produce any material thing; that is, they do not produce finished surfaces on metals, make screws or bolts, bore holes in castings, or turn line shafting. They merely take the energy of the natural agent, which is not in a form available for use, and transform it into motive power for general use.

Hence the element of accuracy as entering into the design of these machines is necessary only for their own efficient operation, and not for the quality of the thing which they produce, as in the case of machine tools. For example, the power furnished by one steam engine to drive a line shaft is as good as that of another as far as the rotating of the shaft is concerned, provided, of course, that both are equipped with the same quality of governing mechanism. The fact that one of the engines has a good adjusting device on the main bearing while the other has not is of no consequence from the standpoint of the line shaft, but it is, of course, of consequence respecting the efficient operation of the engines.

The design of steam engines and similar machines is of a rough nature compared with that of machine tools, as far as the detail of surface is concerned. General accuracy is nevertheless essential for the machine's own sake, but while in the machine tool we deal with thousandths of an inch, in the steam engine hundredths of an inch indicates fine work.

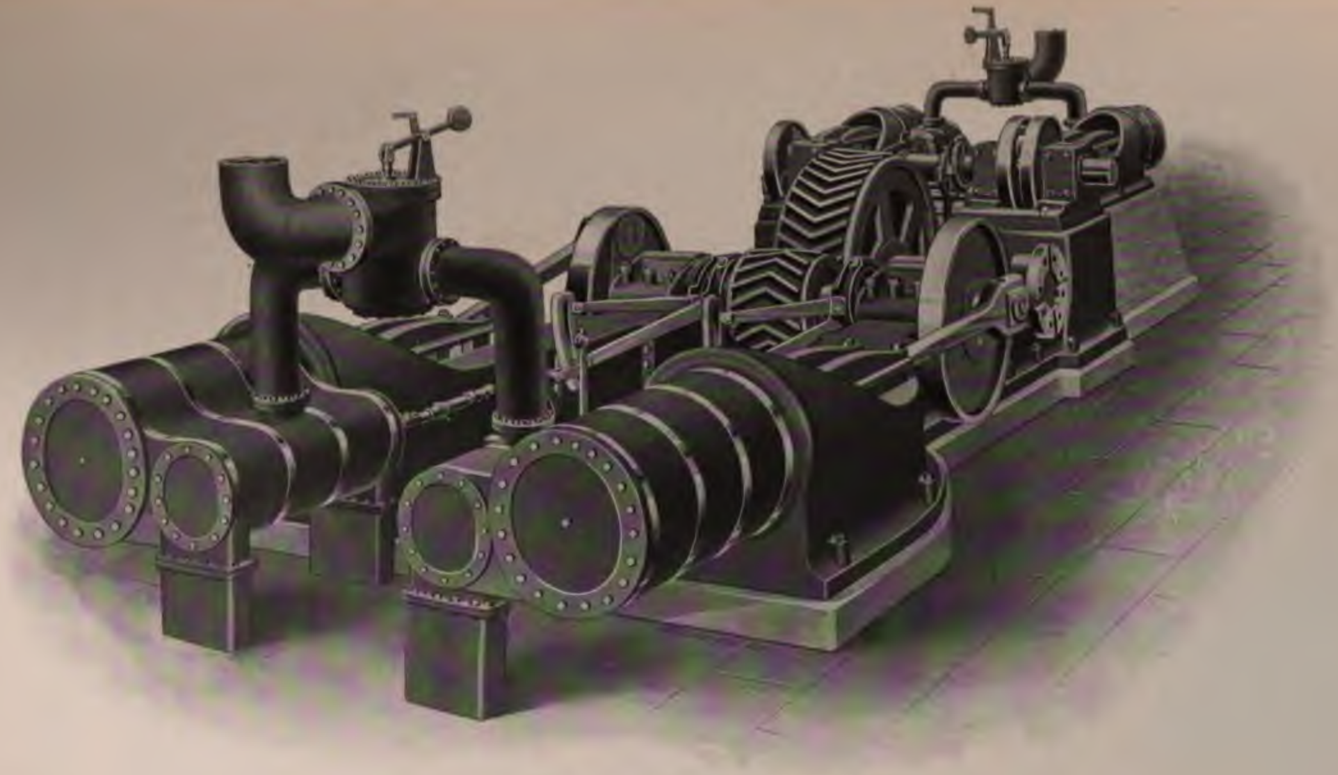
These machines are subject to extremes of temperature that have to be provided for in the design and arrangement of the parts. Being prime movers, controlling the operation of many machines, they must be certain to run during their period of work; hence design and adjustment must be positive, and when the latter cannot be made while running, it must be quickly and definitely accomplished when a stop is made. Simplicity of construction is essential, facilitating cheap and quick repairs. The design should be such that constant attention while running is avoided, the usual attention of the engineer being a safeguard rather than an implied factor of the original design. General rigidity and stiffness are important, also good balancing of the moving parts, and weight for absorption of vibration; otherwise under the constant daily run the machines will tear to pieces not only themselves but their foundations.

As far as external appearance goes in this and subsequent classes to be mentioned we are on a very different basis from that of machine tools. *General* mechanical symmetry of form is aimed at in the design, and the several smaller parts depend for their outline (aside from considerations of strength, which are, of course, always in order) upon the harmonious relation which they bear to the main and fundamental elements of the machine. Such machinery as air compressors, steam engines, pumps, and the like are viewed as a whole, and criticised, not detail by detail, as is the machine tool, but as to general effect of outline observed from some distance. To convey the desired effect to the eye the design must be bold and massive, connections simple and direct, and the smaller parts must not be so dwarfed in size as to appear like delicate ornaments instead of integral parts of the machine. The lines of connected parts must be continuous from one part to the other; and when interrupted by flanges, bosses, or lugs, the latter, which are merely incidental to the former must not be allowed to obscure wholly the main lines of the fundamental pieces.

It is attention to such points as these that marks the difference between well-designed motive-power machinery and that of the opposite character. Even though the little details of fillets and corners and surfaces may have their effect from a close point of view, the design will stand or fall in excellence on its bolder features, as noted above.

Structural Machinery. Examples:—Hoists, cranes, elevators, transfer tables, locomotives, cars, conveyors, cable-ways, etc., etc.

In the two preceding classes that have been noted, cast iron



UNIVERSAL SLABBING MILL ENGINES.

46 x 60 inches and 26 x 30 inches

William Tod Co

in the form of foundry castings enters as the principal material. Steel is utilized for shafts, studs, pins, and keys. Also special forgings, malleable iron and steel castings enter as factors in the production of the machinery discussed. Foundry castings, however, compose the great body of the material used, and the chief problems involved are those of the expert moulding of cast iron, and the handling and finishing of the same. For the operating parts, steel of fine grade is used in highly finished form, expensive because of its fineness, and yet a necessity to the extent it is used. Brass and bronze are used in the same way, generally in connection with the bearings for the shafts.

Structural machinery, on the contrary, uses steel as the basis of its construction. The fundamental structure is built up of plates, channels, beams, and angles; castings, though numerous, are relatively small, being riveted or bolted to the main structure and controlled in their design by its requirements.

Steel is used in this manner partly because the exclusive use of castings is prohibited on account of the excessive weight, and therefore expense, and partly because castings could not be made which would possess the necessary toughness and strength. In many cases the size of the machinery is such that castings, even if they could be made, would not support their own weight. Moreover, machinery of this class is subjected to rough service, and yet must be practically infallible under all conditions, neither being uncertain in operation at critical moments nor entirely failing under an extraordinary load.

The design of structural machinery is tied up to conditions existing largely outside of the locality in which the machinery is built. The steel plates and structural shapes required, being products of the rolling mill, have to conform to the latter's standards. The rivets, bolts and other fastenings have to be in accordance with the established practice of the structural iron worker, in order to permit punching, shearing and bending machinery of regular form to be utilized. Shipment on standard railway cars has to be considered, the design often requiring to be modified to permit this and nevertheless insure positive and accurate assembling in the field.

Steel castings, both large and small, find ready application in this class of work; also steel forgings, requiring to be worked under a heavy hammer and in many cases by specially devised processes.

In structural design less of the actual process of manufacture is under the eye of the designer than in the former classes of machinery which have been considered, and hence more allowance has to be made for things not coming exactly right to the fraction of an inch. It would be bad design to plan any structural piece of work with the same closeness of detail permitted, and in fact required, in the case of machine tools, or even in the case of motive-power machinery. In planning structural work the idea must be carried out, of certainty of operation in spite of roughness of detail and variations of construction. This does not necessarily imply inaccuracy, or shiftless, loosely constructed machinery; on the contrary, quite the reverse. The locomotive, for example, is one of the most refined pieces of mechanism that exists today; and yet the methods applied to the construction of machine tools would prove a failure on the locomotive. The design of a car axle box has to be just right else it will heat and destroy itself; the same is true of the spindle of a fine engine lathe; and yet how rough the former is compared with the latter, and how unsuited either would be for use on the service of the other.

As a general rule structural machinery can be more closely proportioned to theoretically calculated size than can the preceding types. The rolled material of which it is made is of a uniform and homogeneous nature owing to its process of manufacture, hence its every fibre may be counted on to sustain its share of the total load imposed upon it. This is in sharp contrast to the case of cast iron, which is of such a porous and irregular structure that we have to use a large factor of safety to cover this inherent defect.

Steel castings of both small and large size (which are quite apt to be utilized in this class of machinery for parts that can with difficulty be made out of rolled material), if properly designed of uniform thickness, with all corners well filleted and with the channels for the flow of the molten metal direct and ample, are nearly as reliable as rolled steel. In parts subject to excessive vibration, shocks, and sudden wrenchings, as, for example, the side frames or the connecting rod of a locomotive, the forged and hammered material is practically a necessity. This is especially the case when the possible breakage of the part would cause serious consequences involving heavy loss of life and property.

From the several points of view as above considered, it can be readily appreciated that, while structural work is in one sense rough and unpolished, yet it requires, from an engineering standpoint, quite as much breadth of experience and judgment as any of the other types. The fine-tool designer, least of all, perhaps, requires book theory, but does require an extended machine-shop experience. The designer of motive-power machinery needs pure physical theory and shop experience of a large and broad scope. The structural designer is least of all concerned with refined and minute finishing processes, but utilizes his theory absolutely, even though roughly.

Mill and Plant Machinery. Examples:—Rolling mills, mining machinery, crushers, stamps, rock drills, coal cutters, the machinery of blast furnaces and steel mills, tube mills, etc., etc.

This machinery constitutes a class which in the roughness of its operation exceeds all others. Moreover, it is machinery which for the most part is in continuous operation—24 hours per day and 365 days in the year. Hence refinement, even such as might be permitted in the preceding class of Structural Machinery, would be fatal here. The conditions that surround plant machinery are unfavorable in the extreme to the life of any material or metal, and it is not possible to change these conditions or give more than partial protection to the operating parts. Hence the design of such machinery must proceed primarily on the assumption that abuse and neglect, grinding away of surfaces, chemical eating away of metal, flooding of parts with water gritty and corrosive, subjection to sudden bursts of flame and intense heat, etc., will in a relatively short time totally destroy, perhaps, the entire structure.

In view of the continuous nature of the working process, which must be kept up in spite of these almost insurmountable conditions, the problem in each case becomes one of expediency; and the designs and arrangement of machinery must be so worked out that operation, repair, construction, and installation can all go on simultaneously without stopping the continuous process, and with but a small degree of inconvenience to the operation of the plant.

This problem, difficult though it may seem, can be worked out successfully, as is evidenced by the great number of plants of the continuous character operating at high efficiency throughout the world. The engineering and designing skill required to accomplish this, is perhaps of the highest degree met with in modern practice, for in it is involved a working knowledge of the possibilities, if not the detailed designs of machinery included in all classes. And yet, as in the most elementary case of simple design that can be conceived, the result is accomplished in the same way, namely, by studying the conditions (analysis), developing an ideal application to those conditions (theory), and then reducing the ideal design to a practical basis (modification).

A Few Pointed Suggestions on Original Design. Original design deals with the development of original mechanical ideas. The prime requisite for the development of an idea is to understand thoroughly the idea in the rough. See distinctly the mark aimed at, and never lose sight of it. If a method of reaching it is already outlined, understand that also thoroughly and the principles involved. It is impossible to go ahead blindly and hope to come out right. No good machine was ever built that does not stand for hours of concentrated thought on the part of its designer. Good machines never *happen*, they always *grow*.

Just as soon as the object to be accomplished is clearly understood, begin to produce some visible work on the problem. Sketch something. Get some ideas on paper. Ideas on paper suggest other ideas. If the problem, for example, is one of lathe design, sketch a rectangle, and call it the headstock; another rectangle, and call it the footstock; a couple of scratches for the centers; some steps for the cone pulley; three or four lines for the bed; and as many more for the supports. There is now something on paper to look at; the design is begun.

It is much better to stare at this sketch, than into blank space trying to imagine the finished design. No matter how rough the sketch may be, a short study of it will develop some limiting conditions that before were not apparent. Guess at a few rough dimensions; put them on the sketch; develop another view—a plan or a side elevation—all still in the roughest style, without any regard to finished detail. Information will be growing all the while, and the problem will be opening up. At this stage it is probable that the sketch can easily be seen to be wrong in many respects. Perhaps the arrangement will not do at all.

This is a good sign. It shows that the design is progressing. It is a valuable thing to know that certain plans *cannot* be followed. Do not rub out part of the sketch already made and try to remedy it. Begin again. Make another sketch. Sketch paper is cheap. By and by it may prove to be very desirable to have that first rough outline available for comparison; or it may be that some of its ideas can be applied on other sketches. The second sketch may "show up" little or no better than the first. Make another, and another, and another, until the subject is thoroughly digested. It is wonderful how helpful it is to have some marks on paper relative to a design, even though they be of the utmost crudeness. They save imaginative power tremendously; and, even with them, all available powers of imagination will be needed before the design is perfected.

A careful comparison of one's sketches, rejecting here, and approving there, will, little by little, bring about a definite opinion, and the scale drawing can be begun.

As in the case of the first sketch, so in the case of the first scale drawing, get some lines on paper as quickly as possible. Draw something, even if it is nothing more than a straight horizontal line. Do not stare at blank paper for an hour trying to imagine how the tenth or eleventh line is going to be drawn in relation to the first line. Do not worry about the later lines until it is time for them. Draw the first line at once; and, when the second line is drawn, if the first line proves to be wrong, make it right. As in the rough sketch, that first horizontal line is an immense relief from the great waste of blank paper of a fresh sheet. It is something to look at. It is the beginning of a detailed design. If it happens not to be the absolutely correct foundation to build upon, it at least is something to tear down. The main purpose of these preliminary drawings is to keep the mind active on the problem; and advance toward the final accomplishment of the design is often made quite as rapidly by discovering what to tear down as by consistently building up.

When a detail draftsman who has been used to having all his work laid out for him by an expert designer attempts to take up original work for himself, he encounters the drawing of that first line in a way he never did before. He is apt to worry for some time over the possible or impossible results of drawing that first line. If he continue this, he will be sure to fail. The second line is much easier to draw than the first, and the third than the second; and the next hundred will follow on in comparatively smooth sequence, all because of bold action on the first few lines.

And yet, just as the design appears to be progressing smoothly, and the advanced progress of the drawing seems cause for congratulation, careful consideration may disclose a "snag" not previously known to exist in the problem. Further study pursued along the line of this new discovery may show that the whole layout thus far has been radically wrong, and that a fresh start will have to be made. At such a time the young designer is apt to feel that his labor has all been thrown away, and he becomes discouraged. There is, however, no cause for discouragement. Machine Design might almost be defined to be the "successful elimination of snags." It takes some ability to discover an obstacle of this sort; to know a "snag" when an opportunity to see it is given. It takes a good designer to eliminate such a difficulty after it has been found. If there were no "snags" it would not require great ability to design machines. Many machines fail because in them there are a lot of undiscovered "snags." Others fail because the "snags," although discovered, were not eliminated by careful design.

Do not be afraid to make a lot of "first" drawings. It is just as important to digest the design thoroughly by means of scale drawings, as it was to digest it originally by means of the rough sketches. An attempt to make the first drawing of an original design absolutely right would, it is safe to say, produce a poor design, one that could be much improved by further trial. Let the drawings multiply, one after another, until the final one is reached, in which the perfection of detail will eliminate all the bad points of the preceding drafts and incorporate good ones of its own based on the study of the others.

And yet it is often true that the first design laid out, even after many others have been developed, may be found to possess features that render a return to it desirable. This is why it is always better to produce a collection of designs than to attempt to rub out and work over the first one. The best designers usually have a great number of sketches showing how to accomplish a single result. Likewise, they also have a series of layouts to scale, showing in detailed form the development of their various ideas. This is because, without a careful consideration of many methods, they themselves feel incompetent to judge of the best design possible for accomplishing a given result.

Sketches and original designs should always be dated and signed. Different designers may be working on the same problem, and priority of design will never be allowed except upon signed and witnessed papers. It is embarrassing to find, after months and perhaps years have passed since an original drawing was made, that one's rights have been preëmpted merely because there was no date or signature to define them.

In redesigning or modifying an existing machine, never make a change merely for the sake of doing so. Give the good points of the machine a chance, and devote attention in the new design to correcting the bad points. It is in bad taste, if it be not actually childish, to "look wise and suggest a change" in details which happen to have been designed by another party, but which, nevertheless, are by common engineering judgment pronounced good for the special work intended. This element of unfair and selfish criticism has more than a moral bearing. When it is carried into the superintendence of designing work, it extinguishes the personality of the subordinate draftsman; his efficiency as an original thinker is lowered; and narrow designs are produced.

"The best way for a subordinate to dispose of what appears to be a poor suggestion from a superior, is to work it out to the best degree possible." If it turns out to be good the credit of working it out belongs to the man who did it. If it is actually bad, a careful working out will usually develop the fact beyond dispute, and save unprofitable argument. For the success or failure of a machine there is only one argument better than the detail drawings, and that is the machine itself in operation.

Detail drawings, however, are infinitely better prosecutors or defendants than a multitude of wordy counsel.

Summary. The above classification of machinery might be subdivided and extended indefinitely, and on the broad basis on which it is given it doubtless does not cover the entire field. As an illustration, however, not only of types of machinery, but of methods of design and study, it is hoped that it may be of assistance in giving a start to the student of machine design, in whatever class his interests may happen to lie.

It is the general principles of the art which it is important to master. It is not the designing of a locomotive, or a stationary steam engine, or a crane, or an engine lathe, or a rolling mill, which should be sought to be learned, but the designing of *anything* that may confront us. Specializing is sure to come to the designer in the course of his experience, and when it does he merely fits to the particular specialty the principles he knows for all, and practically develops them along that individual line.

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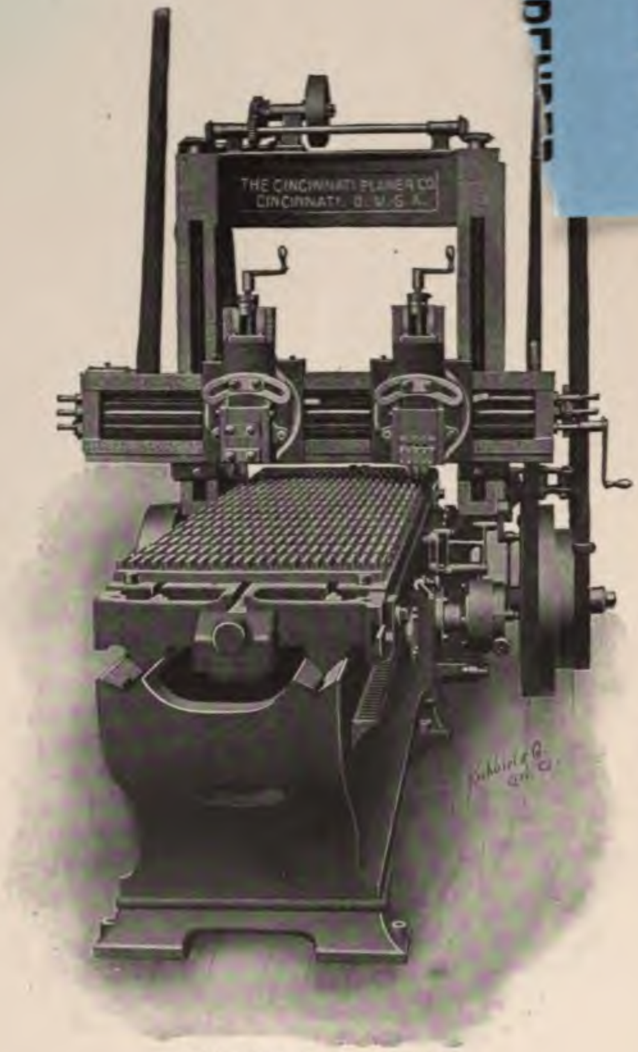


RACK CUTTING PLANER.

MACHINE DESIGN.

PART II.

Introduction. In Part I is illustrated a definite and systematic method of attacking the design of a *machine as a whole.* In Part II the same plan is followed with regard to the detail of its *component parts*, the machine elements which are chosen as illustrations of the method, being the simplest and most familiar forms in common use.

As before, the student must strive to grasp and absorb the *method* of design rather than any specific and established form of a machine part. Part II is not a compendium of design, does not attempt to be complete or exhaustive in any of its chapters, but is condensed and simplified in order to lead the student into systematic mechanical thinking and logical and definite action. Each chapter is intended to stimulate to further and more exhaustive study along lines broader than, and under conditions different from those that can be specified in a general discussion. But no matter how deeply investigation may be carried, or how specialized the study may become, the student must realize that his path of action in any case whatsoever must lie along the lines of *Analysis, Theory*, and *Practical Modification* systematically applied.

BELTS.

NOTATION—The following notation is used throughout the chapter on Belts:

A=Sectional area of belt (square inches) $= bh$.
b=Width of belt (inches).
F=Force of friction at pulley rim (lbs.).
h =Thickness of belt (inches)
μ=Coefficient of friction.
N=Number of revolutions of pulley per minute.
n =Fraction of circumference of pulley embraced by belt.
P=Driving force at pulley rim (lbs.)$=F$.
R =Radius of pulley (feet).
r = Radius of pulley (inches).
T = Initial tension (lbs.).
T_n=Total tension on tight side (lbs.).
T_o=Total tension on slack side (lbs.).
t = Working tension of belt (lbs. per square inch).
V =Velocity of belt (feet per minute).
w =Weight of belt per cubic inch (lbs.).
z = Factor due to centrifugal force.

ANALYSIS. When a belt is stretched over a pair of pulleys, is cut off at the proper length, and is laced together into an endless band, it is evident that as long as the belt is at rest there is a nearly uniform tension in it throughout its length, due to the tightness with which the lacing is drawn up. If the distance between the pulleys is considerable, the weight of the belt itself as it hangs between the pulleys will produce a slightly greater tension next to the pulleys than exists in the middle of the span. This increase of tension due to the weight of the belt would make but little difference in the unit-stress in the material of which the belt is made; hence it may safely be assumed that the tension in the belt when at rest is uniform throughout its entire length.

When we start to transmit power through the belt by turning one of the pulleys, thereby driving the other pulley the condition of stress in the belt is at once materially changed. As the belt is a flexible member, we can transmit only a pull to the other pulley, thereby turning it around, the push which is at the same time given to the other side of the belt merely acting to make the belt sag or become slack. Hence the immediate effect of starting motion in a belt is to change the condition of equal tension throughout its length, to that of unequal tension in the two sides. The driving side is tight, while the other is loose, the former having gained as much tension as the latter has lost, and the sum of the two being practically equal to the sum of the tensions in the two sides of the belt when at rest. This is not strictly true, as will be shown later; but it is sufficiently accurate to form a good basis for the practical design, at least of slow-speed belts.

This condition of tight and slack sides is made possible by the fact that the belt, in being wrapped around the pulleys under tension, has friction on their surfaces. Thus, we can pull hard on one side without slipping the belt around the pulleys, but could not do this if the pulleys were perfectly smooth or frictionless, for in that case the slightest pull on one side would slip the belt around the pulleys. In fact, it would be impossible to produce any pull by means of the driving pulley, for the pulley would merely slip around inside the belt.

The amount of pull we can apply to the belt is therefore limited by the tension at which the belt slips around the pulley. Moreover, since the force of friction between the belt and pulley is dependent upon the normal force with which the belt is pressed against the pulley, and the coefficient of friction between the two, it is evident that the tighter the belt is laced up, and the rougher the surfaces of the pulley and belt, the greater is the force that can be transmitted through the belt. This leads to the conclusion that it would be possible to transmit any amount of power through any belt however small, if the belt were only laced up tight enough.

This conclusion is literally true; but the important fact now comes in, that the strength of the material of which the belt is made is limited, and while theoretically we might be able to accomplish the above, it would be impossible to do so in practice, for at a certain point the belt would break under the strain. Other practical considerations also come in, which fix this limit of power transmission at a point far below the breaking strength of the material.

The complete analysis is not quite as simple as the above, especially for high-speed belts. When the driving side of the belt becomes tight, it stretches and grows longer; and at the same time the other side of the belt becomes slack and grows shorter. But it is not true that the increase in the one side is the same as the decrease in the other, and this fact produces the condition that the sum of the tensions in motion is not quite the same as the sum of the tensions at rest.

Again, when the belt, as it passes around the pulley, changes its straight-line direction to circular motion, each particle of the belt—like a body whirling at the end of a cord about a center of rotation—tends by centrifugal force to fly away from the surface of the pulley, thereby decreasing the normal pressure, and hence the friction. This centrifugal force also changes somewhat the tensions in the belt between the pulleys. As the centrifugal force increases in proportion to the square of the linear velocity, it is evident that the effect is greater at high speeds than at moderate or low speeds.

A further circumstance that affects the driving power of a belt is the stiffness of the leather or other material of which the belt is made. As it passes around the pulley, the belt is bent to conform to the circumference of the pulley, and is again straightened out as it leaves the pulley. Hence the theoretically perfect action is modified somewhat according to the sharpness of the bending and the thickness or flexibility of the belt; in other words, a small pulley carrying a thick-belt would be the worst case for successful calculation on a theoretical basis.

THEORY. The condition of the tight and loose sides of a belt transmitting power, is similar to that of the weighted strap and fixed pulley shown in Fig. 17. If motion is desired of the strap around the pulley, it is necessary to make the weight W_2 of such a magnitude that it will overcome not only the weight W_1, but also the friction between the strap and the pulley. The strap tension T_n is, of course, equal to W_2, and T_o to W_1. The equation showing the balance of forces for the condition when motion is about to occur, is:

$$T_n - T_o = F = P \text{ (driving force).} \qquad \textbf{(5)}$$

If the pulley be free to turn on its axis, instead of being fixed as in Fig. 17, the strap by its friction on the pulley will turn the pulley, and the force of friction F becomes the driving force for the pulley as noted in equation 5 above.

In Fig. 18, let us suppose that W is a weight representing the resistance to be overcome. The tensions T_n and T_o, equal at first owing to stretching the belt tightly over the pulleys at rest, change when an attempt is made to raise the weight by turning the larger pulley; and just as the weight leaves the floor, the equality of moments about the axis of the driven pulley gives the following equation:

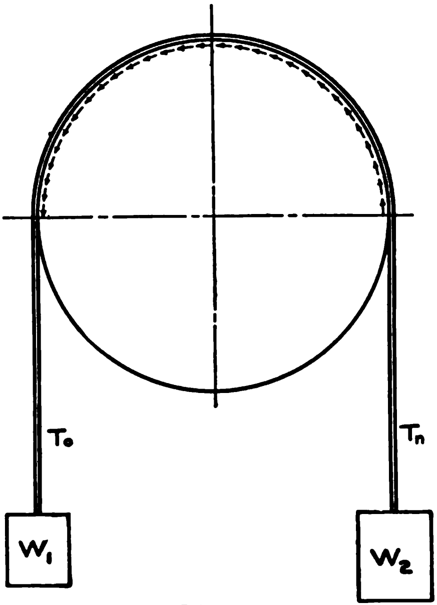


Fig. 17.

$$(T_n - T_o)\, r = F \times r = P \times r = W \times r_1. \qquad \textbf{(6)}$$

This equality of moments remains as long as the motion of the weight is uniform, and represents closely the conditions under which belt pulleys work.

Although we know from the above what the *difference* of the belt tensions is, and what this difference will do when applied to the surface of a given pulley, we do not yet know what either T_n or T_0 actually is; and until we do know, we cannot correctly proportion the belt. Hence we must find another relation between T_n and T_0 which we can combine with equations 5 and 6. This relation is deduced by a process of higher mathematics, which results as follows:

$$\text{Common logarithm } \frac{T_n}{T_0} = 2.729\ \mu\ (1 - z)n. \qquad (7)$$

Treating equations 5 and 7 as simultaneous, values of both T_n and T_0 can be found by the regular algebraic solution. As T_n is the larger, the actual area of belt to provide the necessary strength must be made to depend upon it.

The factor z in equation 7 depends upon the centrifugal force developed by the weight of the belt passing around the pulley. Its value, found from mechanics, is:

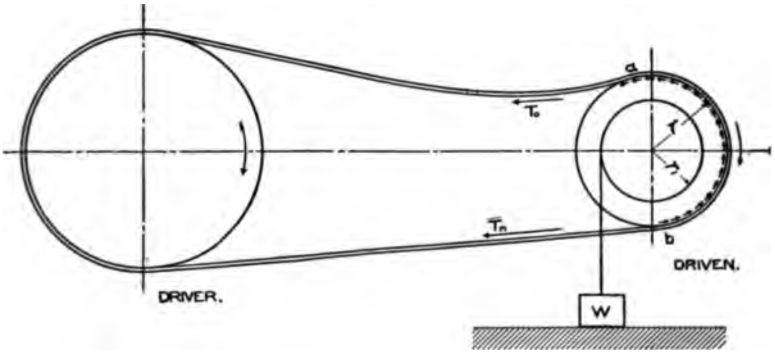


Fig. 18.

$$z = \frac{w \times V^2}{9{,}660 \times t}.$$

Having found the maximum pull on the belt, it now remains to write the equation:

External force = Internal resistance;

or, $$T_n = b \times h \times t. \qquad (8)$$

Usually the most convenient way to handle this equation is to assume h and t, and then solve for b.

Summing up the theoretical treatment of belt design, we simply combine equations 5, 6, 7, and 8, and solve for the quantity desired. Discussion of the constants involved in these equations, and of the practical factors controlling them, is given in the following:

PRACTICAL MODIFICATION. The force of friction F, which is the same as driving force P, depends on:

Coefficient of friction (μ) between belt and pulley;

Tightness of the belt;

Centrifugal force of the belt;

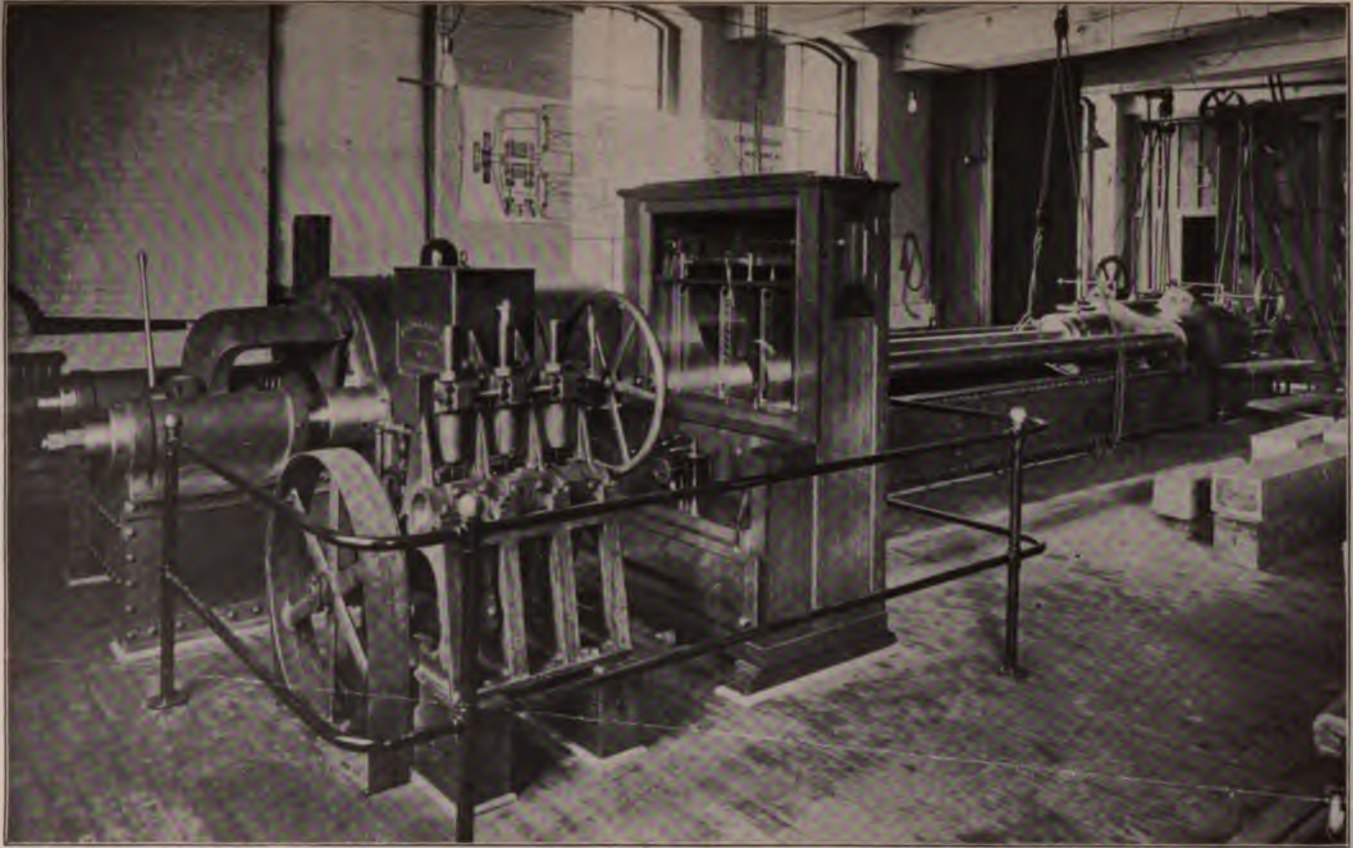
Angle of contact of belt with pulley.

The coefficient of friction (μ), according to experiments and observed operation of belts transmitting power, varies from .15 to .56 for leather on cast iron. An average value consistent with a reasonable amount of slip, the belt being in good running order, is .30. If the belt is oily, or likely to become so in use, a lower value should be taken.

The tighter the belt is drawn up, the greater is the pressure against the pulley, and hence the greater is the force of friction. But if we pull the belt up too tightly, when we begin to drive, T_n becomes too great, and the belt breaks or is under such stress that it wears out quickly. Moreover, the great side pressure on the bearings carrying the shaft produces excessive friction, and the drive is inefficient. This is why a narrow belt driven at high speed is more efficient than a wide belt at slow speed, for we cannot pull up the former as tightly as the latter without overstraining it, and yet it is possible to get the required power out of the narrow belt by running it at high speed.

The centrifugal force is of small importance for low speeds, say of 3,000 feet per minute and less; and it therefore may usually be neglected. The factor z then becomes zero in the expression $1 - z$ in equation 7, and the second member of the equation stands simply $2.729 \times \mu \times n$.

The angle of contact of belt with pulley is important, as a large value gives a great difference between T_n and T_o; and it is desirable to make this difference as great as possible, because thereby the driving force is increased. The loose side of a horizontal belt should always be above, as then the natural sag of the loose



EMERY TESTING MACHINE.

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side due to its slackness tends to increase the angle of contact with the pulley, while the tightening up of the lower side acts against its sag to make the loss of wrap as little as possible. Vertical belts which have the driving pulley uppermost, utilize the weight of the belt to increase the pressure against the surface of the pulley, slightly increasing its capacity for driving. The angle of contact may be artificially increased by a tightening pulley which presses the belt further around the pulley than it would naturally lie. It adds however, the friction of its own bearing, and impairs the efficiency of the drive. For ordinary horizontal belts, the angle of contact is but little more than 180°, and the value of n in equation 7 may be safely assumed at $\frac{1}{2}$ unless the pulleys are of relatively great difference of diameter and very close together.

Strength of Leather Belting. The breaking tensile strength of leather belting varies from 3,000 to 5,000 pounds per square inch. Joints are made by lacing, by metal fasteners, or by cementing. The strength of a laced joint may be about $\frac{7}{10}$, of a metal-fastened joint, about $\frac{1}{2}$, and of a cemented joint, about equal to the full strength of the belt cross-sectional area. The proper working strength of belting depends on the use to which the belt is put. A continuously running belt should have a low tension in order to have long life and a minimum loss of time for repairs. For double leather belting it has been shown that a working tension of 240 pounds per square inch of sectional area gives an annual cost — for repairs, maintenance, and renewals — of 14 per cent of first cost. At 400 pounds working tension, the annual expense becomes 37 per cent of first cost. These results apply to belts running continuously; larger values may be used where the full load comes on but a short time, as in the case of dynamos.

Good average values for working tensions of leather belts are:

Cemented joints,	400	pounds per square inch.
Laced joints,	300	" " " "
Metal joints,	250	" " " "

Horse-Power Transmitted by Belting. If P is the driving force in pounds at the rim of the pulley, and V is the velocity of the belt in feet per minute, the theoretical horse-power transmitted is evidently:

$$\text{H. P.} = \frac{P \times V}{33{,}000}. \qquad (9)$$

It is evident from the above that the horse-power of a belt depends upon two things, the driving force P and the velocity V. If either of these factors is increased, the horse-power is increased. Increasing P means a tight belt. Hence a tight belt and high speed together give maximum horse-power. But a tight belt means more side strain on shaft and journal. Therefore, from the standpoint of efficiency, *use a narrow belt under low tension at as high a speed as possible.*

Empirical rules for horse-power of belting, if used with judgment, give safe results when applied to very general cases. A common rule used by American engineers is:

$$\text{H. P.} = \frac{b \times V}{1{,}000}. \qquad (10)$$

For a double belt, assuming double strength, this becomes:

$$\text{H. P.} = \frac{b \times V}{500}. \qquad (11)$$

With large pulleys and moderate velocities, this may hold good. With small pulleys and high velocities, however, the uncertain stresses induced by the bending of the fibers of the belt around the pulley, and the relatively great loss due to centrifugal force, modify this relation and a safer value for a double belt of the ordinary kind is:

$$\text{H. P.} = \frac{b \times V}{540}; \qquad (12)$$

or, still safer,

$$\text{H. P.} = \frac{b \times V}{700}. \qquad (13)$$

If we compare the theoretical value of equation 9 with the empirical value of equation 10 by putting them equal to each other, thus:

$$\text{H. P.} = \frac{P \times V}{33{,}000} = \frac{b \times V}{1{,}000}.$$

and solve for P, we get :

$$P = 33b. \qquad (14)$$

This develops the fact that the empirical rule of equation 10 assumes a driving force of 33 pounds per inch of width of single belt.

Another way of expressing equation 10 is: A single belt will transmit one horse-power for every inch of width at a belt speed of 1,000 feet per minute.

Speed of Belting. The most economical speed is somewhere between 4,000 and 5,000 feet per minute. Above these values the life of the belt is shortened; also "flapping," "chasing," and centrifugal force cause considerable loss of power. The limit of speed with cast-iron pulleys is fixed at the safe limit for bursting of the rim, which may be taken at one mile per minute.

Material of Belting. Oak-tanned leather, made from the part of the hide which covers the back of the ox, gives the best results for leather belting. The thickness of the leather varies from .18 to .25 inch. It weighs from .03 to .04 pound per cubic inch. The average thickness of double leather belts may be taken as .33 inch, although a variation in thickness from $\frac{1}{4}$ inch to $\frac{7}{16}$ inch is not uncommon. Double leather belts may be ordered light, medium, or heavy.

In a single-thickness belt the grain or hair side should be next to the pulley, for the flesh side is the stronger and is therefore better able to resist the tensile stress due to bending set up where the belt makes and leaves contact with the pulley face. Double leather belts are made by cementing the flesh sides of two thicknesses of belt together, leaving the grain side exposed to surface wear.

Raw hide and semi-raw hide belts have a slightly higher coefficient of friction than ordinary tanned belts. They are useful in damp places. The strength of these belts is about one and one-half times that of tanned leather.

Cotton, cotton-leather, rubber, and leather link belting are some of the forms on the market, each of which is especially adapted to certain uses. For their weights and their tensile and working strengths consult the manufacturers' catalogues.

A prominent manufacturer's practice in regard to the sizes of leather belting will be found useful for comparison, and is indicated in the table on page 12.

Initial Tension in Belt. On the assumption that the sum of the tensions is unchanged, whether the belt be at rest or driving, we should have the following relation :

$$T_n + T_o = 2T;$$

whence,

$$T = \frac{T_n + T_o}{2}. \qquad (15)$$

This is not strictly true, however, as is stated in the "Analysis" of "Belts." It has been found that in a horizontal belt working at about 400 lbs. tension per square inch on the tight side, and having 2 per cent slip on cast-iron pulleys (*i. e.*, the surface of the driven pulley moving 2 per cent slower than that of the driver), the increase of the sum of the tensions when in motion over the sum of the tensions at rest, may be taken at about $\frac{1}{3}$ the value of the tensions at rest. Expressing this in the form of an equation

Sizes of Leather Belting.

WIDTH.	THICKNESS.	
	Single.	Double.
1 inch.	$\frac{5}{32}$ inch.	$\frac{5}{16}$ inch.
2 "	$\frac{3}{16}$ "	$\frac{5}{16}$ "
3 "	$\frac{7}{32}$ "	$\frac{3}{8}$ "
4 "	$\frac{7}{32}$ "	$\frac{3}{8}$ "
5 "	$\frac{7}{32}$ "	$\frac{3}{8}$ "
6 "	$\frac{7}{32}$ "	$\frac{3}{8}$ "
10 "	$\frac{5}{16}$ "	$\frac{3}{8}$ "
12 "	....	$\frac{3}{8}$ "
14 "	....	$\frac{13}{32}$ "
20 "	....	$\frac{7}{16}$ "

$$T_n + T_o = \frac{4}{3}(2T) = \frac{8 \times T}{3}.$$

$$T = \frac{3}{8}(T_n + T_o). \qquad (16)$$

The value of T thus found would be the pounds initial tension to which the belt should be pulled up when being laced, in order to produce T_n and T_o when driving.

This value is not of very great practical importance, as the proper tightness of belt is usually secured by trial, by tightening pulleys, by pulley adjustment (as in motor drives), or by shortening the belt from time to time as needed. It is worth noting, however, that for the most economical life of the belt it would be very desirable in every case to weigh the tension by a spring balance when giving the belt its initial tension. This, however, is not always easy or even feasible; hence it is a refinement with which good practice usually dispenses, except in the case of large and heavy belts.

PROBLEMS ON BELTS.

1. Determine the belt tensions in a laced belt transmitting 50 horse-power at a velocity of 3,500 feet per minute. Suppose that the arc of contact is 180°; weight of belt = .035 pound per cub. in.; and coefficient of friction 25 per cent.

2. What is the width of above belt if it is $\frac{3}{16}$ inch in thickness?

3. What initial tension must be placed on above belt?

4. The main drive pulley of a 120-horse-power water wheel is 6 feet in diameter. A cemented leather belt is to connect the main pulley to a 3-foot pulley on the line shafting in a mill. The horizontal distance between centers of shafting is 24 feet; coefficient of friction, 30 per cent; revolutions per minute of line shafting, 180. Design the belt for this drive.

5. An 8-inch double belt $\frac{3}{8}$ inch thick connects 2 pulleys of 30-inch and 20-inch diameter respectively. The horizontal distance between the centers is 12.5 feet. The coefficient of friction is 0.3, and the weight of belt per cubic inch is 0.035 pound. Working tension, 300 pounds per square inch. Speed of belt 5,000 feet per minute. Lower face of 30-inch pulley is the driving face. Required the H. P. which may be transmitted (theoretically).

6. Compare the theoretical horse-power in problem 5 with that obtained by the use of empirical formula.

PULLEYS.

NOTATION—The following notation is used throughout the chapter on Pulleys:

A = Area of rim (sq. in.).
a = " " arm (" ").
b = Center of pulley to center of belt (inches; practically equal to R).
C_1 = Total centrifugal force of rim (lbs.).
c = Distance from neutral axis to outer fiber (inches).
D = Diameter of pulley (inches).
D_1 = " " hub (").
d_1 = " " bolt at root of thread (inches).
d = Diameter of bolt holes (inches).
g = Acceleration due to gravity (ft. per sec.).
h = Width of arm at any section (inches).
I = Moment of inertia.
L = Length of arm, center of belt to hub (inches).
L_1 = Length of rim flange of split pulley (inches).
l = Length of hub (inches).
N = Number of arms.
n = " " rim bolts, each side.
P = Driving force of belt (lbs.).
P_1 = Force at circumference of shaft (lbs.).
P_2 = Force at circumference of hub (lbs.).
p = Stress in rim due to centrifugal force (lbs. per sq. in.).
R = Radius of pulley (inches).
S = Fiber stress (lbs. per sq. in.).
s = Fiber stress in flange (lbs. per sq. in.).
T = Thickness of web (inches).
t = " " rim (").
t_2 = " " " bolt flange (inches).
T_n = Tension of belt on tight side (lbs.).
T_o = " " " " loose " (").
v = Velocity of rim (ft. per sec.).
w = Weight of material (lbs. per cub. in.).

ANALYSIS. If a flexible band be wrapped *completely* about a pulley, and a heavy stress be put upon each end of the band, the rim of the pulley will tend to collapse just like a boiler tube with steam pressure on the outside of it. A compressive stress is induced which is very nearly evenly distributed over the cross-section of the rim, except at points where the arms are connected thereto. At these points the arms, acting like rigid posts, take this compressive stress. Now, a pulley never has a belt wrapped *completely* round it, the fraction of the circumference embraced by the belt being usually about $\frac{1}{2}$, and seldom, even with a tightener pulley, reaching $\frac{3}{4}$. Assuming the wrap to be $\frac{1}{2}$ the circumference, and that all the side pull of the belt comes on the rim, none being transmitted through the arms to the hub, we then have one-half of the rim pressed hard against the other half by a force equal to the resultant of the belt tensions, which, in this case, would be the sum of them. Dividing the pulley by a plane through its center and perpendicular to the belt, the cross-section of the rim cut by this plane has to take this compressive stress.

This analysis is satisfactory from an ideal standpoint only, for the intensity of stress due to the direct pull of the belt, with the usual practical proportions of rim, would be very small. Moreover, the element of speed has not been considered.

When the pulley is under speed, a set of conditions which complicates matters is introduced. The centrifugal force due to the weight of the rim and arms is no longer negligible, but has an important influence upon the design and material used. This centrifugal force acts against the effect of the belt wrap, tending to reduce the compressive stress, or, overcoming the latter entirely, sets up a tensional stress both in the rim and in the arms. It also tends to distort the rim from a true circle by bowing out the rim between the arms, thus producing a bending moment in the rim, maximum at the points where the rim joins each arm.

It can readily be imagined that the analysis in detail of these various stresses in the rim acting in conjunction with each other is quite complicated — far too much so in fact, to be introduced here. As in most cases of such design, however, one controlling influence can be separated out from the others, and the design based thereon with sufficient margin of strength to satisfy the more obscure conditions. This is rational treatment, and the "theory" will be studied accordingly.

The rim, being fastened to the ends of the arms, tends, when driving, to be sheared off, the resisting area being the areas of the cross-sections of the arms at their point of joining the rim. The force that produces this shearing tendency is the driving force of the belt, or the difference between the tensions of the tight and loose sides.

Again, at the point of connection of the arms to the hub, a shearing action takes place, so that, if this shearing tendency were carried to rupture, the hub would literally be torn out of the arms. Now, viewing the arms as beams loaded at the end with the driving force of the belt, and fixed at the hub, a heavy bending stress is set up, which is maximum at the point of connection to the hub. If the rim were stiff enough to distribute this driving force equally between the arms, each arm would take its proportional share of the load. The rim, however, is quite thin and flexible; and it is not safe to assume this perfect distribution. It is usual to consider that one-half the whole number of arms take the full driving force.

THEORY—Pulley Rim. Evidently it is practically impossible to make so thin a rim that it will collapse under the pull of a belt. As far as the *theory* of the rim is concerned, its proportion probably depends more upon the calculation for centrifugal force than upon anything else.

In order to separate this action from that of any other forces, let us suppose that the rim is entirely free from the arms and hub, and is rotating about its center. Every particle, by centrifugal force, tends to fly radially outward from the center. This condition is represented in Fig. 19. The tendency with which one-half of the rim tends to fly apart from the other is indicated by the force C_1; and the relation between C_1 and the small radial force c for each unit-length of rim can readily be found from the principles of mechanics. The case is exactly like that of a boiler or a thin pipe subjected to uniform internal pressure, which, if carried to rupture, would split the rim along a longitudinal seam.

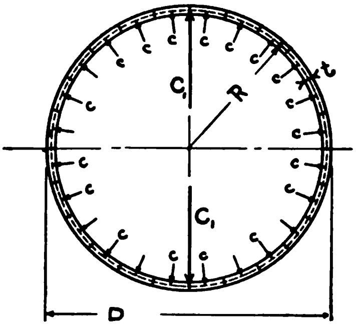


Fig. 19.

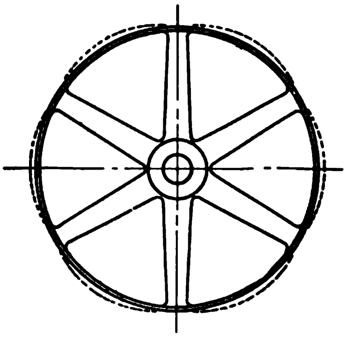


Fig. 20.

The tensile stress thus induced per square inch can be found by simple mechanics to be:

$$p = \frac{12wv^2}{g}; \qquad (17)$$

or, since $w = 0.26$ pound, and $g = 32.2$ feet per second,

$$p = 0.097\,v^2 \ \left(\text{say } \frac{v^2}{10}\right); \qquad (18)$$

and, if p be taken equal to 1,000 pounds per square inch, which is as high as it is safe to work cast iron in this place,

$$v = 100 \text{ feet per second.} \qquad (19)$$

This shows the curious fact that the intensity of stress in the rim is directly proportional to the square of the linear velocity, and wholly independent of the area of cross-section. It is also to be noted that 100 feet per second is about the limit of speed for cast-iron pulleys to be safe against bursting.

If we wish to consider theoretically the rim together with the arms as actually connected to it, we get a much more complicated relation. This condition is shown in Fig. 20, where the rim, expanding more than the arms, bulges out between them. This makes the rim act something like a continuous beam uniformly loaded; but even then the resulting stress is not clearly defined on account of the variable stretch in the arms. Investigation on this basis is not needed further than to note that it is theoretically better, in the case of a split pulley, to make the joint close to the arms, rather than in the middle of a span.

Pulley Arms. The centrifugal force developed by the rim and arms tends to pull the arms from the hub. On the belt side, this is balanced to some extent by the belt wrap, which tends to compress the arm and relieve the tension. On the side away from the belt, the centrifugal action has full play, but the arm is usually of such cross-section that the intensity of this stress is very low. It may safely be neglected.

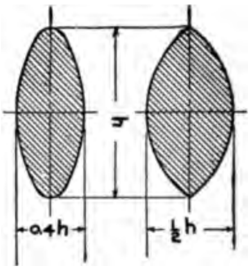


Fig. 21.

The rim being very thin in most cases, its distributing effect cannot be depended on, hence the driving force of the belt may be taken entirely by the arms immediately under the portion of the belt in contact with the pulley face. For a wrap of 180° this means that only one-half of the pulley arms can be considered as effective in transmitting the turning effort to the hub. Each of these arms is a lever fixed at one end to the hub and loaded at the other. A lever of this description is called a "cantilever" beam, its maximum moment existing at its fixed end. The load that each of these beams may be subjected to is $\frac{P}{\frac{N}{2}}$, and therefore the maximum external moment at the hub is $\frac{2PL}{N}$. From mechanics we know that the internal moment of resistance of any beam section is $\frac{SI}{c}$, and that equilibrium of the beam can be satisfied only when the external moment is equal to the internal moment of resistance of the beam section. Equating these two, we have:

$$\frac{2PL}{N} = \frac{SI}{c}. \qquad (20)$$

The arms of a pulley are usually of the elliptical or segmental cross-section, and may be of the proportions shown in Fig. 21. For either of these sections the fraction $\frac{I}{c}$ is approximately equal to $0.0393h^3$. For convenience (the error caused being on the safe side), L may be taken as equal to the full radius of the pulley R, whence

$$\frac{2PR}{N} = \frac{2\,T_n - T_o)R}{N} = 0.0393Sh^3, \qquad (21)$$

in which S may be from 2,000 to 2,250 for cast iron

Taking moments about the center of the pulley, and solving for P_2, the force acting at the circumference of the hub, we have:

$$\frac{2PR}{N} = \frac{P_2D_1}{2};$$

or

$$P_2 = \frac{4PR}{ND_1} \qquad (22)$$

The area of an elliptical section is π times the product of the half axes. With the proportions of Fig. 21, this becomes:

$$a = \pi \times 0.2h \times 0.5h = \pi h^2. \qquad (23)$$

Equating the external force to the internal shearing resistance, we have:

$$\frac{4PR}{ND_1} = \pi h^2 S_s;$$

[illegible] (24)

in which the shearing stress S_s may run from 1,500 to 1,800 for cast iron.

Although both bending and shearing stresses as calculated above exist at the base of the arms, the bending is, in practically every case, the controlling factor in the design of the arms. An arm-section large enough to resist bending would have a very low intensity of shear.

If the number of arms be increased indefinitely, we come to a continuous arm or web, in which the bending action is eliminated. It may still shear off at the hub, where the area of metal is the least, at minimum circumference. In this case the area under shearing stress is $\pi D_1 T$; and the force at the circumference of the hub, as before, is :

$$P_2 = \frac{4PR}{ND_1}.$$

Equating external force to internal shearing resistance, we have :

$$\frac{4PR}{ND_1} = \pi D_1 T S_s;$$

$$\text{or,} \quad S_s = \frac{4PR}{\pi D_1^2 TN}. \quad \textbf{(25)}$$

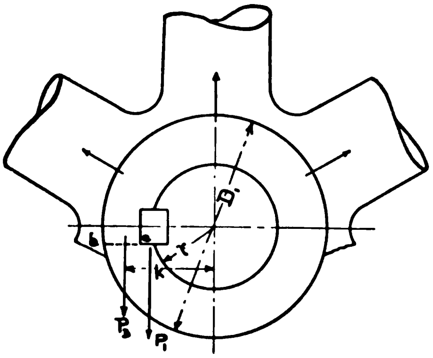


Fig. 22.

Pulley Hub. As in the case of the arms, centrifugal force does not play much part in the design of the hub of a pulley. The hub is designed principally to carry the key, and through it transmit the turning moment to the shaft. Considered thus, the hub may tear along the line of the key or crush in front of the key.

For example, in Fig. 22, if the connection with the lower arms be neglected, and the upper arms be held fast while a turning force P_1, at the surface of the shaft, is transmitted to the hub through the key, then the metal of the hub directly in front of the key is under crushing stress; and the metal along the line *eb*, from the corner to the outside, is under tensile stress. This condition is the worst that could possibly happen, because the bracing effect of the lower arms has been neglected, and the key is located between arms.

Taking moments about the center of the shaft, the value of the force at the shaft circumference, or the "key pull," is:

$$P_1 = \frac{P\,R.}{r} \qquad (26)$$

Now $\frac{P_1}{P_2} = \frac{k}{r}$, k being the distance from the center of shaft to center of eb, and the area of metal which is subjected to the tearing action P_2 is $l \times eb$. Equating the external force to the internal resistance, and assuming that the stress is equally distributed over the area $l \times eb$, we have:

$$P_2 = \frac{r}{k} P_1 = \frac{r}{k} \times \frac{P\,R}{r} = S \times l \times e\,b;$$

or,

$$S = \frac{PR}{k \times l \times eb}. \qquad (27)$$

The intensity of crushing on the metal in front of the key, due to force P_1, depends upon the thickness of the key, and is properly discussed later under "Keys."

PRACTICAL MODIFICATION—Pulley Rim. The theoretical calculation for the thickness of the rim may give a thickness that could not be cast in the foundry, and the section in that case will have to be increased. As light a section as can be readily cast will usually be found abundantly strong for the forces it has to resist. A minimum thickness at the edge of the rim is about $\frac{3}{16}$ inch; and as the pulleys increase in size, the rim also must be made thicker; otherwise the rim will cool so much more quickly than the arms, that the latter, on cooling, will develop shrinkage cracks at the point of junction.

For a velocity of 6,000 feet per minute, we find from equation 18 that the tension in pounds per square inch, in the rim, due to centrifugal force, is 970. Though this in itself is a low value, yet the uncertain nature of cast iron, its condition of internal stress, due to casting, and the likely existence of hidden flaws and pockets, have established the usage of this figure as the highest safe limit for the peripheral speed of cast-iron pulleys. It is easily remembered that *cast-iron pulleys are safe for a linear velocity of about one mile per minute.*

To prevent the belt from running off the pulley, a "crown" or rounding surface is given the rim. A tapered face, which is more easily produced in the ordinary shop, may be used instead. This taper should be as little as possible, consistent with the belt staying on the pulley; $\frac{1}{2}$ inch per foot each way from the center is not too much for faces 4 inches wide and less; while above this width $\frac{1}{4}$ inch per foot is enough. As little as $\frac{1}{8}$ inch total crown has been found to be sufficient on a 24-inch face, but this is probably too little for general service.

Instead of being "crowned," the pulley may be flanged at the edges; but flanged pulley rims chafe and wear the edge of the belt.

The inside of the rim of a cast-iron pulley should have a taper of $\frac{1}{2}$ inch per foot to permit easy withdrawal from the foundry mould. This is known as "draft." If the pattern be of metal, or if the pulley be machine-moulded, the greater truth of the casting does not require that the inside of the rim be turned, as the pulley, at low speeds, will be in sufficiently good balance to run smoothly. For roughly moulded pulleys, and for use at high speeds, however, it is necessary that the rim be turned on the inside to give the pulley a running balance.

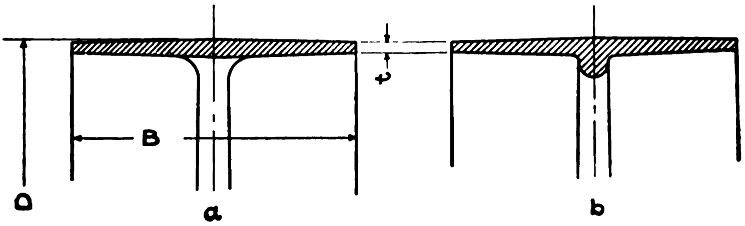


Fig. 23.

Fig. 23 shows a plain rim *a* also one stiffened by a rib *b*. Where heavy arms are used this rib is essential so that there will not be too sudden change of section at the junction of rim and arm, and consequent cracks or spongy metal.

Pulley Arms. The arms should be well filletted at both rim and hub, to render the flow of metal free and uniform in the mould. The general proportions of arms and connections to both hub and rim may perhaps be best developed by trial to scale on the drawing board. The base of the arm being determined, it may gradually taper to the rim, where it takes about the relation of ⅔ to ¾ the dimensions chosen at the hub. The taper may be modified until it looks right, and then the sizes checked for strength.

Six arms are used in the great majority of pulleys. This number not only looks well, but is adapted to the standard three-jawed chucks and common clamping devices found in most shops. Elliptical arms look better than the segmental style. The flat, rectangular arm gives a very clumsy and heavy appearance, and is seldom found except on the very cheapest work.

A double set of arms may be used on an excessively wide face, but it complicates the casting to some extent.

Although a web pulley may be calculated for shear at the hub, yet it will usually be found that with a thickness of web intermediate between the thickness of the rim and that of the hub, which will satisfy the casting requirements, the requirements as to strength will be fully met.

Pulley Hub. The hub should have a taper of ½ inch per foot draft, similar to that of the inside of the rim. The length of the hub is arbitrary, but should be ample to prevent rocking on the shaft. A common rule is to make it about ¾ the face width of the pulley.

The diameter of the hub, aside from the theoretical consideration given above, must be sufficient to take the wedging action of a taper key without splitting. This relation cannot well be calculated. Probably the best rule that exists is the familiar one that the hub should be twice the diameter of the shaft. This rule, however, cannot be literally adhered to, as it gives too small hubs for small shafts and too large ones for large shafts. It is always well to locate the key, if possible, underneath an arm instead of between the arms, thus gaining the additional strength due to the backing of the arm.

SPLIT PULLEYS.

ANALYSIS and THEORY. The split pulley is made in halves and provided with bolts through flanges and bosses on the hub for holding the two halves together. When the pulley is in place on the shaft, bolted up as one piece, it is subjected to the same forces as the simp [illegible] Hence its general design follows the same principles, and we need only study the fastening of the two halves, and the effect of this fastening on the detail of rim and hub.

The simplest stress we have to consider on the rim bolts is one of pure tension, due to the centrifugal force of the halves of the pulley, A safe assumption to make is that the rim is free from the arms and hub, as in the simple pulley, and that the centrifugal force developed by it has to be taken by the rim bolts alone. In other words, consider the rim bolts as belonging entirely to the rim, and make them as strong as the rim, leaving the hub bolts to take the centrifugal force of the arms and hub, and the spreading tendency due to the key.

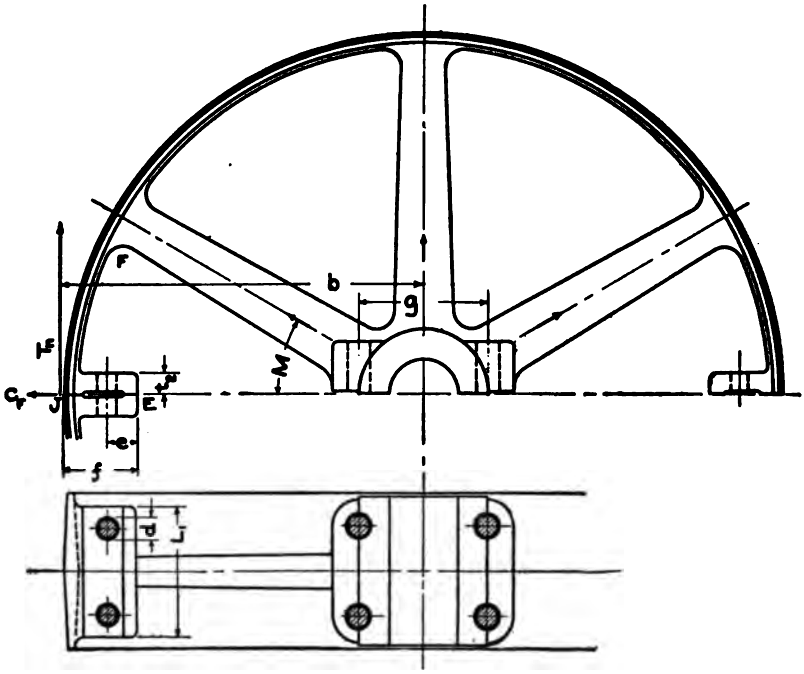


Fig. 24.

Another tensile stress is induced in the rim bolts by the fact, that, having made an open joint in the rim, and in addition placed the extra weight of lugs there, the centrifugal action at this point is increased, and at the same time a point of weakness in the rim introduced. Referring to Fig. 24, the rim flanges EJ tend to fly out due to the centrifugal force C_F. This tends to open the joint J at the outside of the rim ; to throw a bending stress on the rim, maximum at the point F ; and to "heel" the rim flanges about the point E. The rim bolts acting on the leverage e about the point E must resist these tendencies, and are thereby put in tension.

Referring to equation 18, we find the intensity of stress due to the centrifugal force of the rim in lbs. per square inch to be :

$$p = \frac{v^2}{10}.$$

If A is the sectional area of the rim in square inches, this means that the total strength of the rim is represented by $\frac{Av^2}{10}$. The strength of a bolt is represented by the expression $\frac{S\pi d_1^2}{4}$. If, now, there are n bolts in the flange, the total resisting force of the bolts is $\frac{nS\pi d_1^2}{4}$; and the equation representing equality of strength between rim and bolts is :

$$\frac{Av^2}{10} = \frac{nS\pi d_1^2}{4}, \quad (28)$$

from which, by a proper assumption of the fiber stress S, which should be low, the opening-up tendency of the joint being neglected, the diameter at the root of the thread d_1 may be calculated, and the nominal bolt diameter chosen. Reference to the table for strength of bolts, given in the chapter on Bolts, Studs, etc., will be found convenient.

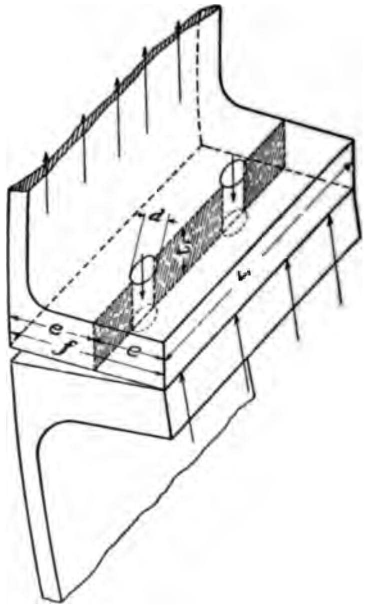
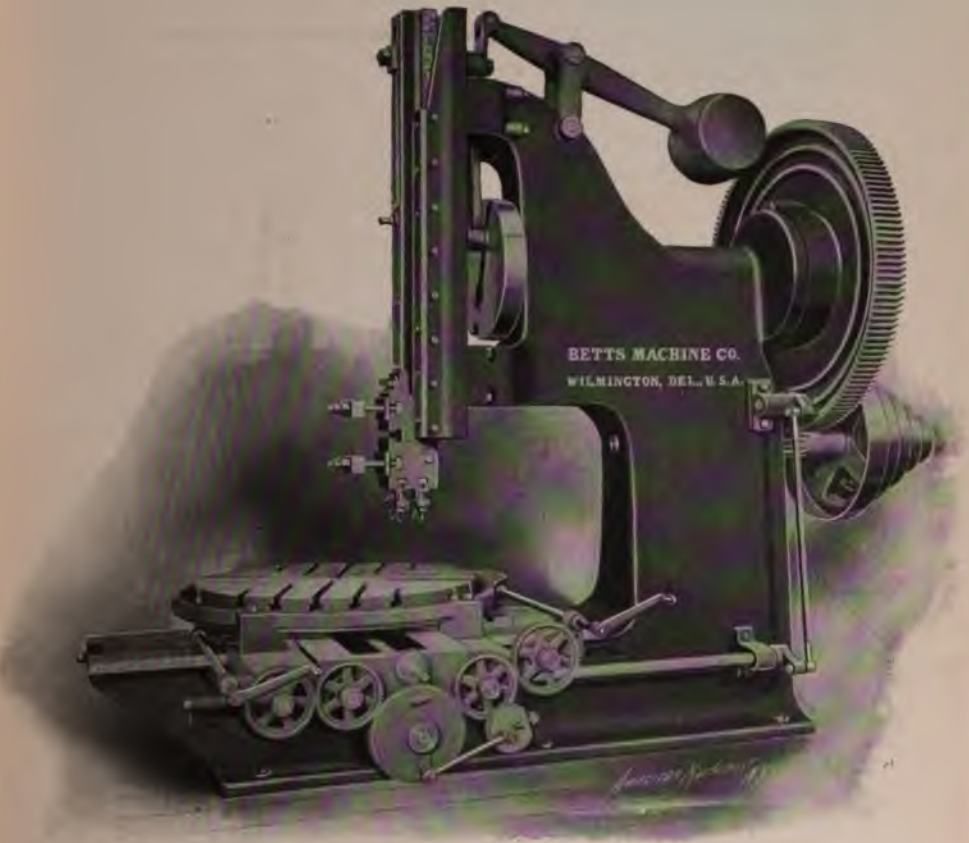


Fig. 25.


BETTS MACHINE CO.
WILMINGTON, DEL., U.S.A.

21-INCH SLOTTING MACHINE.

It is very doubtful if the tension on the flange bolts, due to the "heeling" about E can be calculated with sufficient accuracy to be of much value. It is probably better to assume S at a low value, say 4,000, and, in addition, for large and high-speed pulleys, stiffen the rim by running a rib between the flange and the adjacent arm. It is evident that if we make the rim so stiff that it cannot deflect, there will be no "heeling" about E; and the bolts will be well proportioned by the preceding calculation, giving them equal strength to that of the rim section.

For the bolt flange itself, any tendency to open at the joint J would cause it to act like a beam loaded at some point near its middle with the bolt load, and supported at J and E. This condition is shown in Fig. 25. Probably the weakest section would be along the line of the bolt centers. We have just noted that the carrying capacity of the bolts is $\frac{nS\pi d_1^2}{4}$. Hence, assuming that $e = \frac{1}{2}f$, which is about the worst case which could happen, we have a beam of length f loaded at the middle with $\frac{nS\pi d_1^2}{4}$ and supported at the ends. Equating the external moment to the internal moment, we have :

$$\frac{nS\pi d_1^2}{4} \times \frac{f}{4} = \frac{s(L_1 - nd)t_2^2}{6}, \qquad (29)$$

from which the fiber stress s in the flange may be calculated and judged for its allowable value.

L_1 may be assumed a little narrower than the pulley face; and t_2 from 1 inch to 2 inches or more, depending on the thickness of the rim.

The hub bolts doubtless assist the rim bolts in preventing the halves of the pulley from flying apart. They also clamp the hub tightly to the shaft, preventing any looseness on the key. Their function is a rather general one; and the specific stress which they receive is practically impossible to calculate. As a matter of fact, if the hub bolts were left out entirely, the pulley would still drive fairly well, but general rigidity and steadiness would be impaired. Hence the size of the hub bolts is more a practical question than one involving calculation. The rim bolts should be figured first, and their size determined on; then the hub bolts can be judged in proportion to the rim bolts, the diameter of shaft, the thickness and length of the hub, and the general form of the pulley. Often appearance is the deciding factor, it being manifestly inconsistent to associate small fastenings with large shafts or hubs, even though the load be actually small.

PRACTICAL MODIFICATION. Practical considerations are chiefly responsible for the location of the joint in a split pulley between the arms instead of directly at the end of an arm, where theoretically it would seem to be required. It is usually more convenient in the foundry and machine shop to have the joint between the arms; so we generally find it placed there, and strength provided to permit this. It is possible, however, to provide a double arm, or a single split arm, in which case the joint of the pulley comes at the arm, and the "heeling" action of the rim flanges is prevented.

The rim bolts should be crowded as close as possible to the rim in order to reduce the stress on them, and also the stress in the flange itself. The practical point must not be forgotten, however that the bolts must have sufficient clearance to be put into place beneath the rim.

While it is evident that the rim bolts are most effective in taking care of the centrifugal action of the halves, yet in small split pulleys it is quite common to omit the rim bolts and to use the hub bolts for the double purpose of clamping the shaft and holding the two halves together. The pulley is cast with its rim continuous throughout the full circle, and it is machined in this form. It is then cracked in two by a well-directed blow of a cold chisel, the casting being especially arranged for this along the division line by cores so set that but a narrow fin of metal holds the two parts together. This provides sufficient strength for casting and turning, but permits the cold chisel to break the connection easily.

SPECIAL FORMS OF PULLEYS.

The plain cast-iron pulley has been used in the foregoing discussion as a basis of design. A pulley is, however, such a common commercial article, and finds such universal use, that special forms, which can be bought in the open market, are not only cheaper but better than the plain cast-iron pulley, at least for regular line-shaft work.

Cast iron is a treacherous and uncertain material for rims of pulleys. It is not well suited to high fiber stresses; hence the range of speed permissible for pulley rims of cast iron is limited. Steel and wrought iron, having several times the tensional strength of cast iron, and being, moreover, much more nearly homogeneous in texture, are well suited for this work; one of the best pulleys on the market consists of a steel rim riveted to a cast-iron spider. Such an arrangement combines strength and lightness, without increasing complication or expense.

The all-steel pulley is a step further in this direction. Here the rim, arms, and hub are each pressed into shape by specially devised machinery, then riveted and bolted together. This pulley is strictly a manufactured article, which could not compete with the simpler forms unless built in large quantities, enabling automatic machinery to be used. Large numbers of pulleys are built in this way, and are put on the market at reasonable prices.

Wood-rim pulleys have been made for many years, and, except for their clumsy appearance, are excellent in many respects. The rim is built up of segments in much the same way as an ordinary pattern is made, the segments being so arranged that they will not shrink or twist out of shape from moisture. The hubs may be of cast iron, bolted to wooden webs, and carrying hard-wood split bushings, which may be varied in bore within certain limits so as to fit different sizes of shafting. The wooden pulley is readily and most often used in the split form, thus enabling it to be put in position easily at any point of a crowded shaft. It is often merely clamped in place, thus avoiding the use of keys or set screws, and not burring or roughening the shaft in any way.

PROBLEMS ON PULLEYS.

1. Calculate the tensile stress due to centrifugal force in the rim of a cast-iron pulley 30 inches in diameter, at 500 revolutions per minute.

2. The driving force of a belt on a 36-inch pulley is 800 lbs., and the belt wrap about 180°. Calculate proportions of el-

liptical arms to resist bending, the allowable fiber stress being 2,000.

3. A pulley 12 inches in diameter, $\frac{5}{8}$-inch web, 4-inch diameter hub, transmits 25 horse-power at a belt speed of 3,000 ft. per minute. Calculate the maximum shearing stress in the web.

4. In Fig. 24 assume the following data: $L_1 = 7$ inches; $t_2 = 1$ inch; $e = 1\frac{1}{4}$ inches; $f = 3$ inches; area of rim $= 3$ sq. in.; allowable tensile stress in rim 1,000 lbs. per sq. in. Calculate the diameter of the rim bolts.

5. Calculate the fiber stress in the rim bolt flange along the line of the bolts.

SHAFTS.

NOTATION—The following notation is used throughout the chapter on Shafts:

A_0=Angular deflection (degrees).
B =Simple bending moment (inch-lbs.).
B_e=Equivalent bending moment (inch-lbs.).
c =Distance from neutral axis to outer fiber (inches).
d, d_0, d_2, d_3, d_4=Diameters of shaft (inches).
d_1=Internal diameter of shaft (inches).
E=Direct modulus of elasticity (a ratio).
e =Transverse deflection (inches).
G=Transverse modulus of elasticity (a ratio).
H=Horse-power (33,000 ft.-lbs. per minute).
I =Moment of inertia.
K=Distance between bearings (inches).
L =Length along shaft (inches).
L_1, L_2=Length of bearings (inches.)
M =Distance between bearings (feet.)
N =Number of revolutions per minute.
P =Driving force of belt (lbs.).
P_1=Load applied as stated (lbs.).
R =Radius at which load as stated acts (inches).
S =Fiber stress, tension, compression, or shearing (lbs. per sq. in.).
T =Simple twisting moment (inch-lbs.).
T_e=Equivalent twisting moment (inch-lbs.).
T_n=Tension in tight side of belt (lbs.).
T_o=Tension in loose side of belt (lbs.).
W=Load applied as stated (lbs.).

ANALYSIS. The simplest case of shaft loading is shown in Fig. 26. The equal forces W, similarly applied to the disc at the distance R from its center, tend to twist the shaft off, the tendency being equal at all points of the length L between the disc and the post, to which the shaft is rigidly fastened. The fastening to the post, of course, in this ideal case, takes the place of a resisting member of a machine. A state of pure torsion is induced in the shaft; and any element, such as *ca*, is distorted to the position *cb*, *aob* being the angular deflection for the distance L.

The case of Fig. 27 is illustrative of what occurs when a belt pulley is substituted for the simple disc. Here the twisting action is caused by the driving force of the belt, which is $T_n - T_o = P$, acting at the radius R. Torsion and angular deflection exist in the shaft, as in Fig. 26. In addition, however, another stress of a different kind has been introduced; for not only does the 'shaft tend to be twisted off, but the forces T_n and T_o, acting together, tend to bend the shaft, the bending moment varying with every section of the shaft, being nothing at the point *o*, and maximum at the point *c*. This combined action is the most common of any that we find in ordinary machinery, occurring in nearly every case with which we have to deal.

In Fig. 27, if the forces T_n and T_o be made equal, there will be no tendency at all to twist off the shaft, but the bending will remain, being maximum at the point *c*. This condition is illustrative of the case of all ordinary pins and studs in machines. In this sense, a pin or a stud is simply a shaft which is fixed to the frame of the machine, there being no tendency to turning of the pin or stud itself. The same condition would be realized if the disc in Fig. 27 were loose upon the shaft. In that case, the bending moment would be caused by $T_n + T_o$ acting with the leverage L. Of course there would have to be some resistance for $T_n - T_o$ to work against, in order that torsion should not be transmitted through the shaft. This condition might be introduced by having a similar disc lock with the first one by means of lugs on its face, thus receiving and transmitting the torsion.

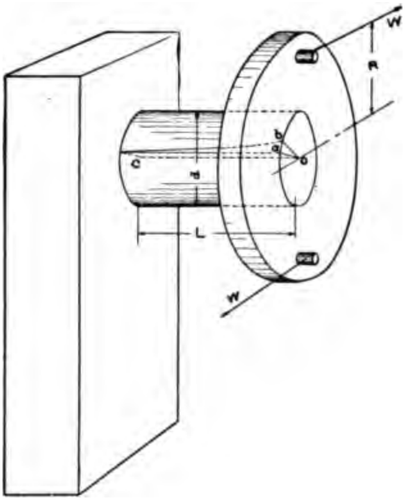


Fig. 26.

If the distance L becomes very great, both the angular deflection due to twisting, and the sidewise deflection due to bending, become excessive, and not permissible in good design. This trouble is remedied by placing a bearing at some point closer to the disc, which, as it decreases L, of course, decreases the bending moment and therefore the transverse deflection. The angular deflection can be decreased only by bringing the resistance and load nearer together.

The above implies, of course, that the diameter of the shaft is not changed, it being obvious that increase of diameter means increase of strength and corresponding decrease of both angular and transverse deflection.

If the speed of the shaft be very high, and the distance between bearings, represented by L, be very great, the shaft will take a shape like a bow string when it is vibrated, and smooth action cannot be maintained.

It is necessary to carry the cases of Figs. 26 and 27 but a single step farther to illustrate the actual working conditions of shafting in machines. Suppose the rigid post to have the shaft passing clear through it, and to act as a bearing, so that the shaft can freely rotate in it, the resistance being exerted somewhere beyond. The twisting moment will be unchanged, also the bending moment; but the effect of the bending moment will be on each particle of the shaft in succession, now putting compression on a given particle, and then tension, then compression again, and so on, a complete cycle being performed for each revolution. This

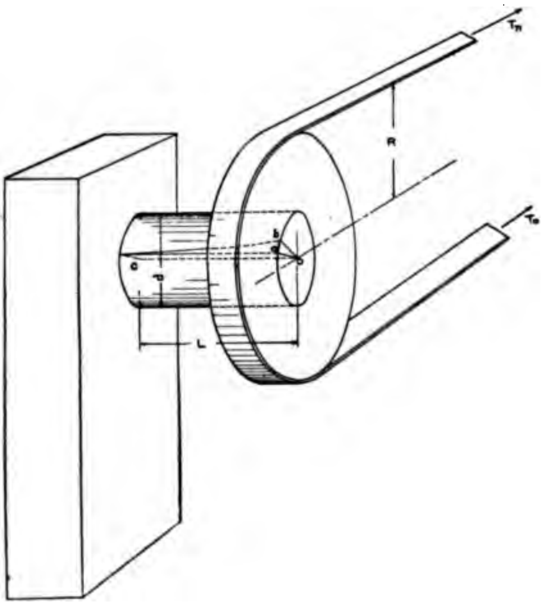


Fig. 27.

brings out a very important difference between the bending stress in pins and the bending stress in rotating shafts. In the one case the bending stress is non-reversing; in the other, reversing; and a much higher fiber stress is permissible in the former than in the latter.

THEORY—Simple Torsion. In the case of simple torsion the stress induced in the shaft is a shearing one. The external moment acts about the axis of the shaft, or is a polar moment; hence in the expression for the moment of the internal forces, the polar moment of inertia must be used. Now, from mechanics we have:

$$T = \frac{SI}{c};$$

and $\frac{I}{c} = \frac{d^3}{5.1}$ (for circular section of diameter d);

therefore, $$T = \frac{Sd^3}{5.1}, \qquad (30)$$

from which the diameter for any given twisting moment and fiber stress can readily be found.

For a hollow shaft this expression becomes:

$$T = \frac{S(d_0^4 - d_1^4)}{5.1d_0}. \qquad (31)$$

Simple Bending. The stresses induced in a pin or shaft under simple bending are compression and tension. The external moment in this case is transverse, or about an axis across the shaft; hence the direct moment of inertia is applicable to the equation of forces.

$$B = \frac{SI}{c};$$

and $\frac{I}{c} = \frac{d^3}{10.2}$ (for circular section of diameter d);

therefore, $$B = \frac{Sd^3}{10.2}. \qquad (32)$$

For a hollow shaft or pin this expression becomes:

$$B = \frac{S(d_0^4 - d_1^4)}{10.2d_0}. \qquad (33)$$

Combined Stresses. In the greater number of cases met with in practice, we find two or more simple stresses acting at the same time, and, although the shaft may be strong enough for any one of them alone, it may fail under their combined action. The most common cases are discussed below.

Tension or Pressure Combined with Bending. In Fig. 28, the load W produces a tension acting over the whole area of d, due to its direct pull. It also produces a bending action due to the leverage R, which puts the fibers at B in tension and those at the opposite side in compression. It is evident, therefore, that by taking the algebraic sum of the stresses at either side we shall obtain the net stress. It is also evident that the greatest and controlling stress will occur on the side where the stresses add, or on the tension side. Hence, from mechanics,

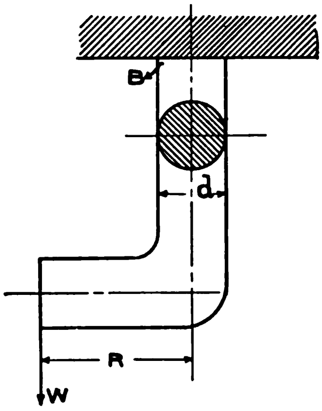


Fig. 28.

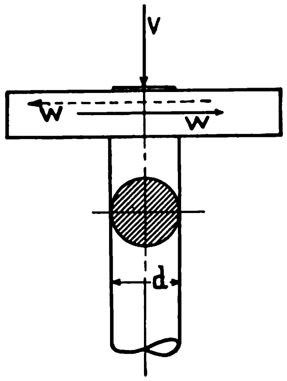


Fig. 29

$$W = \frac{\pi d^2 S}{4};$$

or, $$S = \frac{4W}{\pi d^2} \text{ (due to direct tension).} \qquad (34)$$

Also, $$WR = \frac{S d^3}{10.2};$$

or, $$S = \frac{10.2\ WR}{d^3} \text{ (due to bending).} \qquad (35)$$

Hence the combined tensional stress acting at the point B, or, in fact, at any point on the extreme outside of the vertical shaft toward the force W, is:

$$S = \frac{4W}{\pi d^2} + \frac{10.2\ WR}{d^3}. \qquad (36)$$

If W acted in the opposite direction, the greatest stress would still be at the side B, but would be a compression instead of a tension, of the same magnitude as before.

Tension or Compression Combined with Torsion. In Fig. 29, V might be the end load on a vertical shaft; and the two forces W might act in conjunction with it as in the case of Fig. 26, at the radius R. This case is not very often met with. It is usually possible to combine the moments, find an equivalent moment of a simple kind, and use the corresponding simple fiber stress. In the case in question we have a direct stress to be combined with a shearing stress, and mechanics gives us the following solution:

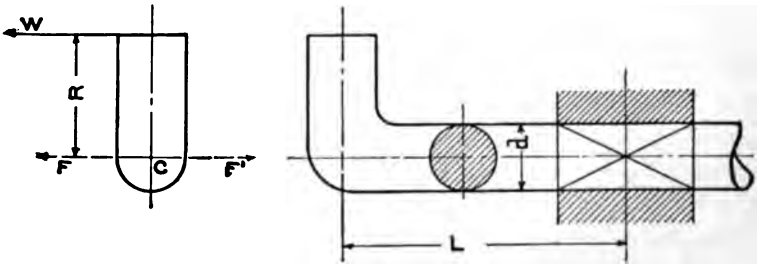


Fig. 30.

Let S_s = simple shearing stress (lbs. per sq in.).
Let S_c = simple compressive stress (lbs. per sq. in.).
Let S_{rs} = resultant shearing stress (lbs. per sq. in.).
Let S_{rc} = resultant compressive stress (lbs. per sq. in.).

We then have :

$$2WR = \frac{S_s d^3}{5.1};$$

or,

$$S_s = \frac{5.1(2WR)}{d^3}. \qquad (37)$$

Also,

$$V = \frac{\pi d^2 S_c}{4};$$

or. [illegible] (38)

Now, from [illegible] Merriman's Mechanics"—[illegible] values for the [illegible] is the critical [illegible] its diameter:

[illegible] (39)

Also, [illegible] (40)

Bending Combined with Torsion. [illegible] W acts not [illegible] against the [illegible] the maximum [illegible] the length [illegible] that point [illegible] plicated. [illegible] let us introduce [illegible] equal to W, [illegible] changing the [illegible] that W and [illegible] and that F acts [illegible] Fl. Wl, [illegible]

If, now, [illegible] alent bending [illegible] the fibers of [illegible] culation of the [illegible] cases of simple [illegible] relation is given us [illegible]

$$B_e = \frac{B}{2} + \frac{1}{2}\sqrt{B^2 + T^2}. \qquad (41)$$

$$T_e = B + \sqrt{B^2 + T^2}. \qquad (42)$$

[illegible]ressions are true in relation to each other, on the assumption [illegible] the allowable fiber stress S is the same for tension, compression, and shearing. For the material of which shafts are usually made, this is near enough to the truth to give safe and practical results. Using the expressions for internal moments of resistance as previously noted for circular sections, we then have :

$$B_e = \frac{Sd^3}{10.2}. \qquad (43)$$

Also,

$$T_e = \frac{Sd^3}{5.1}. \qquad (44)$$

Either equation may be used ; the diameter d will result the same whichever equation is taken. For the sake of simplicity, equation 42 is generally preferred, equation 44 being taken in conjunction with it.

The expression $\sqrt{B^2 + T^2}$ is one that would be a long and tedious task to calculate. By inspection it is readily seen that this quantity can be graphically represented by means of a right-angled triangle having B and T as the sides. We may then lay down on a piece of paper, to some convenient scale, the moments B and T as the sides of a right-angled triangle, when, upon measuring the hypothenuse, we can easily read off to the same scale $\sqrt{B^2 + T^2}$. Even if the drawing is made to a small scale, the accuracy of the reading will be sufficient to enable the value for d to be solved very closely. This graphical method is illustrated in Part I.

Deflection. For a shaft subjected to pure torsion, as in Fig. 26, the angular deflection due to the load may be carried to a certain point before the limit of working fiber stress is exceeded. The equation worked out from mechanics for this condition, is:

$$A^\circ = \frac{584\ TL}{Gd^4}, \qquad (45)$$

which at once gives the number of degrees of angular deflection for a shaft whose modulus of elasticity, torsional moment, and length are known.

The shearing modulus of elasticity of ordinary shaft steel runs from 10,000,000 to 13,000,000, giving as an average about 12,000,000.

By the well-known relation of "Hooke's law" (stresses proportional to strains within the elastic limit of the material), we have:

$$\frac{A^\circ}{360^\circ} = \frac{SL}{\pi G d};$$

or

$$S = \frac{A \pi G d}{360\ L}. \qquad (46)$$

A twist of one degree in a length of twenty diameters is a usual allowance. Substituting A = 1, L = 20d, and G = 12,000, 000, we have:

$$S = 5{,}240 \text{ (nearly)}. \qquad (47)$$

This is a safe value for shearing fiber stress in steel. In fact, in calculations for strength, even for reversing stresses, the usual figure is 8,000 (lbs. per square inch), thus indicating that the relation of one degree to twenty diameters is well within the limit of strength.

For a hollow shaft the above formula becomes :

$$A^\circ = \frac{584\ TL}{G(d_0^4 - d_1^4)}. \qquad (48)$$

Transverse deflection occurs when the shaft is subjected to a bending moment. It may therefore exist alone or in conjunction with angular deflection. Transverse deflection of shafts, however, rarely exists up to the point of limiting fiber stress, because before that point is reached the alignment of the shaft is so disturbed that it is not practicable as a device for transmitting power. A transverse deflection of .01 inch per foot of length is a common allowance ; but it is impossible to fix any general limit, as in many cases this figure, if exceeded, would do no harm, while in others—such as heavily loaded or high-speed bearings—even the figure given might be fatal to good operation.

The formula for transverse deflection, deduced from mechanics, varies with the system of loading. The three most common conditions only are given below, reference to the handbook being necessary if other conditions must be satisfied:

Fixed at one end, loaded at the other,

$$\delta = \frac{WL^3}{3\ EI}. \qquad (49)$$

Supported at ends, loaded in middle,

$$e = \frac{WL^3}{48 EI}. \qquad (50)$$

Supported at ends, loaded uniformly,

$$e = \frac{5WL^3}{384 EI}. \qquad (51)$$

For transverse deflection the direct modulus of elasticity must be used, for the fibers are stretched or compressed, instead of being subjected to a shearing action. The most usual value of the direct modulus of elasticity for ordinary steel is 30,000,000, and is denoted in most books by the symbol E. Both the shearing and direct moduli of elasticity are really nothing but the ratio of the stress to the strain produced by that stress, it being assumed that the given material is perfectly elastic. A material is supposed to be perfectly elastic up to a certain limit of stress, and it is within this limit that the relation as above holds good.

Expressed in the form of an equation this would be:

$$E = \frac{S}{\frac{e}{L}} = \frac{SL}{e}. \qquad (52)$$

Centrifugal Whirling. If a line shaft deflect but slightly, due to its own weight, or the weight or pressure of other bodies upon it, and then be run at a high speed, the centrifugal force set up increases the deflection, and the shaft whirls about the geometrical line through the centers of the bearings, causing vibration and wear in the adjoining members. It is evident that the practical remedy for this tendency in a shaft of given diameter and speed is to locate the bearings sufficiently close to render the action of small effect.

Many formulæ might be given for this relation, each being based on different assumptions. Perhaps as widely applied and as simple as any, is the "Rankine" formula, which sets the limit of length between bearings for shafts not greatly loaded by intermediate pulleys or side strains:

$$M = 175 \sqrt{\frac{d}{N}}. \qquad (53)$$

Horse-Power of Shafting. Horse-power is a certain specific rate of doing work, *viz.*, 33,000 foot-pounds per minute. Hence, to find the horse-power that a shaft will transmit, we must first find the work done, and then relate it to the speed. Take, for example, the case of a pulley, the symbols being the same as before —namely, $P =$ driving force at rim of pulley (lbs.); $R =$ radius of pulley (inches); $N =$ number of revolutions per minute; and $H =$ horse-power. Then,

$$\text{Work} = \text{force} \times \text{distance} = P \times (2\pi RN) = H \times 33{,}000 \times 12;$$

or,

$$PR = \frac{63{,}025H}{N}. \qquad \textbf{(54)}$$

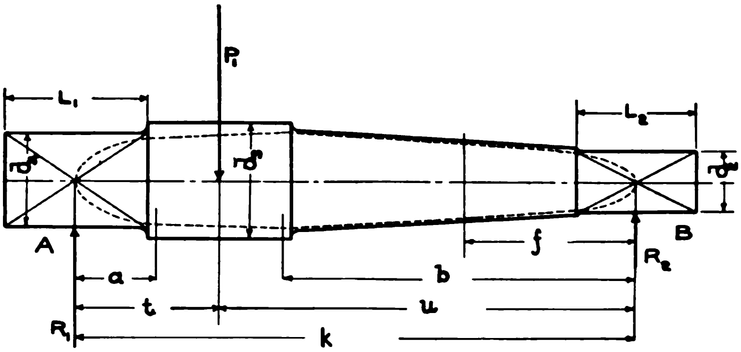


Fig. 31.

This is one of the most useful equations for calculations involving horse-power. By it the number of inch-pounds torsion for any horse-power can be at once ascertained.

It should be clearly noted, however, that in this equation the bending moment does not enter at all. Hence any shaft based in size on *horse-power alone*, is based on *torsional moment alone*, bending moment being entirely neglected. In many cases the bending moment is the controlling one as to limiting fiber stress. Hence empirical shafting formulæ depending upon the horse-power relation are unsafe, unless it is definitely known just what torsional and bending moments have been assumed.

The only safe way to figure the size of a shaft is to find accurately what torsional moment and bending moment it has to sustain, and then combine them according to equ[illegible] or 42 introducing the element of speed as basis for assumption of a high or low working fiber stress.

PRACTICAL MODIFICATION. The practical methods of handling the theoretical shaft equations have reference to the fit of the shaft within the several pieces upon it. The running fit of a shaft in a bearing is usually considered to be so loose that the shaft could freely deflect to the center of the bearing. This is doubtless an extreme view of the case, but it is the only safe assumption. Hence a shaft running in bearings (see Fig. 31) is supposed to be supported at the centers of those bearings, and its theoretical strength is based on this supposition.

For a tight or driving fit upon the shaft, a safe assumption to make is that there is looseness enough at the ends of the fit to permit the shaft to be stressed by the load a short distance within the faces of the hub, say from ½ inch to 1 inch. For example, referring to Fig. 31, suppose P_1 to be the transverse load, exerted through a hub fast upon the part of the shaft d_3. Taking moments about the center of one bearing, and solving for the reaction at the center of the other, we have:

$$P_1\,u = R_1\,K;$$

or,

$$R_1 = \frac{P_1\,u}{K}. \qquad (55)$$

Also,

$$P_1\,t = R_2\,K;$$

or,

$$R_2 = \frac{P_1\,t}{K}. \qquad (56)$$

Now, as far as the part of shaft d_3 is concerned, it may depend for its size on the bending moment $R_2\,b$, or on $R_1\,a$. The reason the lever arm is not taken to the point directly under the load P_1, is because it is not practically possible to break the shaft at that point, on account of the reinforcement of the hub, which is tightly fitted upon it. Trying these moments to see which is the greater, we shall find that the greater moment always occurs in connection with the longer lever arm. Hence $R_2\,b$ will be greater than $R_1\,a$. We then write the equation of *external moment = internal moment:*

$$R_2\,b = \frac{S\,d_3^3}{10.2};$$

or,
$$d_3 = \sqrt[3]{\frac{10.2\ R_2 b}{S}}. \qquad (57)$$

For the size of bearing A we have the maximum bending moment:

$$R_1 \frac{L_1}{2} = \frac{S\, d_4^3}{10.2};$$

or,
$$d_4 = \sqrt[3]{\frac{10.2\ R_1 L_1}{2\ S}}. \qquad (58)$$

For the size of bearing B we have the maximum moment:

$$R_2 \frac{L_2}{2} = \frac{S\, d_2^3}{10.2};$$

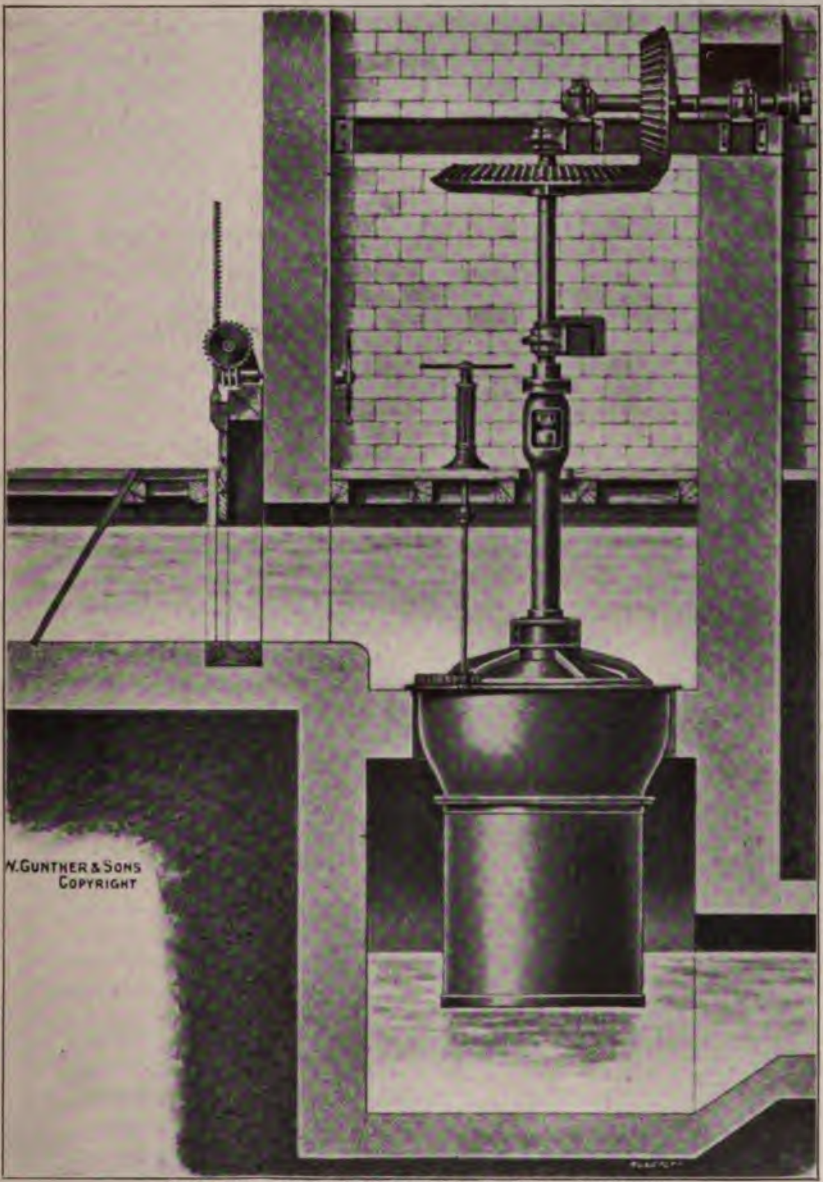
or,
$$d_2 = \sqrt[3]{\frac{10.2\ R_2 L_2}{2\ S}}. \qquad (59)$$

The above calculations are, of course, on the assumption that no torsion is transmitted either way through this axle. We should in that case have combined torsion and bending. This has been made sufficiently clear in preceding paragraphs and in Part I, to require no further illustration.

The dotted line in Fig. 31 shows the theoretical shape the axle should take under the assumed conditions. The practical modification of this shape is obvious. At the shoulders of the shaft the corners should not be sharp, but carefully filleted, to avoid the possible starting of a crack at those points.

Often the diameter of certain parts of a shaft may be larger than strength actually calls for. For example, in Fig. 31, the part d_3 need only be as large as the dotted line; but it is obvious that unless the key is sunk in the body of the shaft, the hub could not be slipped into place over the part d_4. If, however, the diameter d_3 be made large enough so that the bottom of the key will clear d_4, the rotary cutter which forms the key way in d_3 will also clear d_4, and the key way can be more easily produced.

In cases where fits are not required to be snug, a straight shaft of cold-rolled steel is commonly used. Here any parts fastened on the middle of the shaft have to be driven over a considerable length of the shaft before they reach their final position. Moreover, there is no definite shoulder to stop against, and measurement has to be resorted to in locating them.



GENERAL ARRANGEMENT OF JONVAL TURBINE.
Central Engineering Works, Oldham, Eng.

It does not pay to turn any portion of a cold-rolled shaft, unless it be the very ends, for relieving the "skin tension" in such material is sure to throw the shaft out of line and necessitate subsequent straightening.

Turned-steel shafts for machines may with advantage be slightly varied in diameter wherever the fit changes; and although the production of shoulders costs something, yet it assists greatly in bringing the parts to their exact location, and enables the workman to concentrate his best skill on the fine bearing fits, and to save time by rough-turning the parts that have no fits.

Hollow shafts are practicable only for large sizes. The advantages of removing the inner core of metal, aside from some specific requirement of the machine, are that it eliminates all possibility of cracks starting from the checks that may exist at the center, permits inspection of the material of a shaft, and, in case of hollow-forged shafts, gives an opening for the forging mandrel. In the last case, the material is improved by a rolling process.

The material most common for use in machine shafting is the ordinary "Machinery Steel," made by the Bessemer process. This steel is apt to be "seamy," and often contains checks and flaws that are detected only upon sudden and unexpected breakage of a part apparently sound. This characteristic is a result of the process employed in the manufacture of the steel, and thus far has never been wholly eliminated. **Bessemer steel** is, nevertheless, a very useful material, and the above weakness is not so serious but that this kind of steel can be used with success in the great majority of cases.

When a more homogeneous shaft is desired, **open-hearth steel** is available. This is a more reliable material to use than the Bessemer, and costs somewhat more. It makes a stiff, true, fine-surfaced shaft, high-grade in every respect. It is usually specified for armature shafts of dynamos and motors.

Steels of special strength, toughness, and elasticity are made under numerous processes. **Nickel steel** is perhaps the most conspicuous example. While for this steel a high price has to be paid, yet its great strength, in connection with other valuable qualities, makes it a material extremely valuable for service where light weight is essential, or where contracted space demands small size.

The range of strength of these various steels is so great that it is well-nigh useless to go into a discussion of it here. Reference should be had to the extended discussions of the handbooks, and to special trade pamphlets. A study of the possibilities of steel in its various forms for use in shafting, is very valuable as a basis for design, as it can almost be said that a machine consists chiefly of a "collection of shafts with a structure built round them." The shafts are like a core, and evidently the size of the core determines the shell about it.

PROBLEMS ON SHAFTS.

1. Required the twisting moment on a shaft that transmits 30 horse-power at 120 revolutions per minute.

2. Find the diameter of a steel shaft designed to transmit 50 horse-power at 150 revolutions per minute.

3. Assuming same data as in Problem 1, find the diameters of a hollow shaft for a value of $S = 8,000$.

4. A belt on an idler pulley embraces an angle of 120 degrees. Assuming tension of belt 1,000 pounds on each side, and pulley located midway between bearings, which are 30 inches from center to center, what is the diameter of shaft required?

5. Calculate the diameter of a steel shaft designed to transmit a twisting moment of 400,000 inch-pounds and also to take a bending moment of 300,000 inch-pounds.

6. Find the angular deflection in a 4-inch shaft 20 feet long when subjected to a load of 5,500 pounds applied to an arm of 30-inch radius. Assume transverse modulus of elasticity equal to 12,000,000.

7. The overhung crank of a steam engine has a force of 32,000 lbs. at the center of the crank pin, which is 12 inches from the center of the shaft bearing, measured parallel to the shaft. The radius of crank-arm is 10 inches. Assume S equal to 10,000. Calculate the diameter of the crank shaft.

8. On a short, vertical steel shaft the load is 5,000 pounds. A gear, 36 teeth, $1\frac{1}{8}$ diametral pitch, at top of shaft, transmits a load of 4,000 pounds at the pitch line. Safe shear = 7,500. What is the diameter of the shaft?

SPUR GEARS.

NOTATION—The following notation is used throughout the chapter on Spur Gears:

b = Breadth of rectangular section of arm (inches).

M, M_1 = Revolutions per minute.

μ = Coefficient of friction between teeth.

C = Width of arm extended to pitch line (inches).
c = Distance from neutral axis to outer fiber (inches).
D = Pitch diameter of gear (inches).
F = Face of gear (inches).
f = Clearance of tooth at bottom (inches).
G = Thickness of arm extended to pitch line (inches).
H = Thickness of tooth at any section (inches).
h = Depth of rectangular section of arm (inches).
I = Moment of inertia.
K = Thickness of rim (inches).
L = Distance from top of tooth to any section (inches).
N = Number of teeth.
n = Number of arms.
P = Diametral pitch (teeth per inch of diameter).
P^1 = Circular pitch (inches).
Q, Q_1 = Normal pressure between teeth (lbs.).
R, R_1 = Resultant pressure between teeth (lbs.).
r, r_1 = Radius of pitch circles (inches).
S = Fiber stress of material (lbs. per sq. in.).
s = Addendum of tooth (inches) = Dedendum of tooth.
t = Thickness of tooth at pitch line (inches).
W = Load at pitch line (lbs.).
y = Coefficient for "Lewis" formula.

ANALYSIS. If a cylinder be placed on a plane surface, with its axis parallel to the plane, an attempt to rotate the cylinder about its axis would cause it to roll on the plane.

Again, if two cylinders be provided with axial bearings, and be slightly pressed together, motion of one about its axis will cause a similar motion of the other, the two surfaces rolling one on the other at their common tangent line. If moved with care, there will be no slipping in either of the above cases—which is explained by the fact that no matter how smooth the surfaces may appear to be, there is still sufficient roughness to make the little irregularities interlock and act like minute teeth.

The magnitude of the force possible to be transmitted depends not only on the roughness of the surfaces, but on the amount of pressure between them. Suppose that one cylinder is a part of a hoisting drum, on which is wound a rope with a weight attached. We can readily make the weight so great that, no matter how hard we press the two cylinders together, the driving cylinder will not turn the hoisting cylinder, but will slip past it. If now, instead of increasing the pressure, which is detrimental both to cylinders and bearings of same, we increase the coarseness of the surfaces, or, in other words, put teeth of appreciable size on these surfaces, we attain the desired result of positively driving without excessive side pressure.

These artificial projections, or teeth, must fit into one another; hence the surfaces of the original cylinders, having been broken up into alternate projections and hollows, have entirely disappeared to the eye; they nevertheless exist as ideal or imaginary surfaces, which roll together with the same surface velocities as if in bodily form, provided that the curves of the teeth are correctly formed. Several mathematical curves are available for use as tooth outlines, but in practice the **involute** and **cycloidal curves** are the only ones used for this purpose.

The ideal surfaces are known as **pitch cylinders** or **pitch circles.** In Fig. 32 is shown an end view of such a pair of cylinders in contact at their pitch point P. In gear calculations we assume that there is no slip between the pitch circles, acting as driving cylinders; hence the speeds of the two pitch circles at the pitch point are equal. If M and M_1 be the revolutions per minute of the cylinders respectively, r and r_1 their radii, then

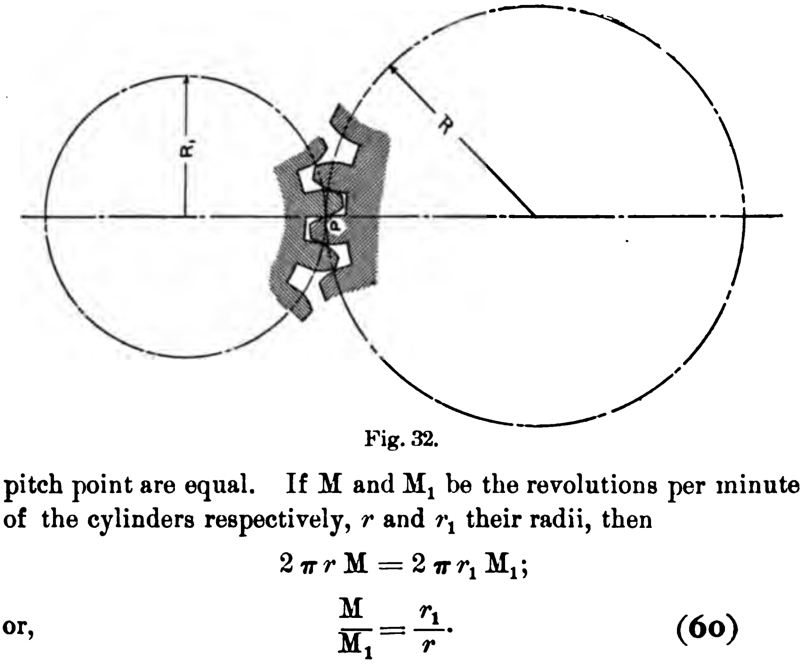


Fig. 32.

$$2\pi r M = 2\pi r_1 M_1;$$

or,
$$\frac{M}{M_1} = \frac{r_1}{r}. \qquad (60)$$

That is, the number of revolutions varies inversely as the radii.

The simple calculation as above is the key to all calculations involving gear trains in reference to their speed ratio.

Fig. 33 represents cycloidal teeth in the two extreme positions of beginning and ending contact. The normal pressure Q or Q_1 between the teeth in each position acts through the pitch point O, as it must always do in order to insure the condition of ideal rolling of the pitch circles, and the velocity ratio proportional to $\frac{r_1}{r}$ As the surfaces of the teeth slide together, frictional resistance is produced at their point of contact. This force is widely variable, depending on the material and condition of the tooth surfaces, whether smooth and well lubricated, or rough and gritty. As this resistance acts in conjunction with the normal force between the teeth, we may construct a parallelogram of forces on these two as a base, the resultant pressure between the teeth being slightly changed thereby, as shown in Fig 33.

Assuming a coefficient of friction μ, the force of friction is μ Q or μ Q_1 and the resultant pressure R or R_1.

Tooth B of the FOLLOWER is therefore under a heavy bending moment measured by the product RL, L being the perpendicular distance from the center of the tooth at its base to the line of the force. This tooth also has a relatively small compressive stress due to the resolved part of R along the radius, and a relatively small shearing stress due to the resolved part of R along a tangent to the pitch circle.

Tooth D of the driven wheel or FOLLOWER has a relatively large shearing stress, a small bending moment, and practically no direct compressive stress.

Tooth A of the driving wheel or DRIVER has a relatively large shearing stress, a small bending moment, and small compressive stress.

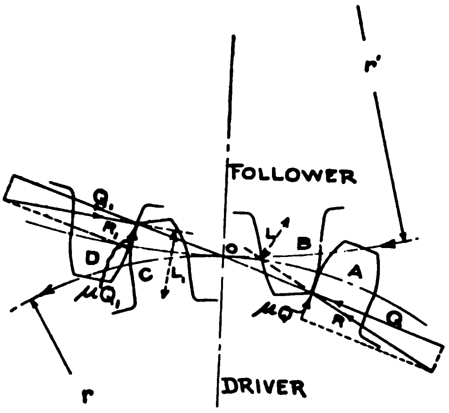


Fig. 33.

Tooth C of the DRIVER has a large bending moment, but small compressive and shearing stresses.

The conditions as noted above are not those of every pair of gears, in fact they vary with every difference of pitch circle, or of detail and position of tooth. It is true, however, that in nearly all cases in practice the bending stress is the controlling one from a theoretical standpoint. Moreover, the designer must consider the form and strength of the tooth when it is under the condition of maximum moment. This evidently, from the above, occurs at the beginning of contact, for the follower teeth; and at the end of contact, for the driver teeth. In the particular case illustrated in

Fig. 33, if the material in both gears were the same, tooth C, being the weaker at the root, would probably break before B; but if C were of steel, and B of cast iron, B might break first.

It will be noticed that R is nearly parallel to the top of the tooth; and it may easily happen that the friction may become of such a value that it will turn the direction of R until it lies along the top of the tooth exactly, which is the condition for maximum moment. For strength calculations it is usual to consider this condition as existing in all cases.

At the beginning of contact there is more or less shock when the teeth strike together, and this effect is much more evident at high speeds. There is also at the beginning of contact a sort of chattering action as the driving tooth rubs along the driven tooth.

Uniform distribution of pressure along the face of the tooth is often impaired by uneven wear of the bearings supporting the gear shafts, the pressure being localized on one corner of the tooth. The same effect is caused by the accidental presence of foreign material between the teeth. Again, in cast gearing, the spacing may be irregular, or, on account of draft on the pattern, the teeth may bear at the high points only. While it is usual to consider that the load is evenly distributed along the face of the tooth, yet the above considerations show that *an ample margin of strength must always be allowed* on account of these uncertainties.

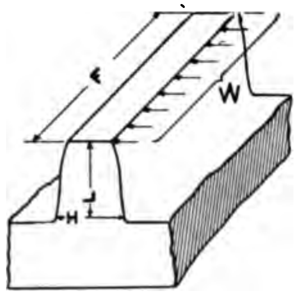


Fig. 34.

When the number of teeth in the mating gears is high, the load will be distributed between several teeth; but, as it is almost certain that at some time the proper distribution of load will not exist, and that one tooth will receive the full load, it is considered that practically the only safe method is so to design the teeth that a single tooth may be relied upon to withstand the full load without failure.

THEORY. Based on the Analysis as given, the theory of gear teeth assumes that one tooth takes the whole load, and that this load is evenly distribut[illegible] h and acts parallel with its base, thus reducing the condition of the tooth to that of a cantilever beam. The magnitude of this load at the top of the tooth is taken for convenience the same as the force transmitted at the pitch circle. This condition is shown in Fig. 34. Equating the external moment to the internal moment, we then have, from mechanics:

$$WL = \frac{SI}{c} = \frac{SFH^2}{6}. \qquad (61)$$

The thickness H is usually taken either at the pitch line or at the root of the tooth just before the fillet begins; and L, of course, is dependent on the tooth dimensions. The formula is most readily used when the outline of the tooth is either assumed or known, a trial calculation being made to see if it will stand the load, and a series of subsequent calculations followed out in the same way until a suitable tooth is found. This method is pursued because there are certain even pitches which it is desirable to use; and it is safe to say that any calculation figured the reverse way would result in fractional pitches. The latter course may be used, however, and the nearest even pitch chosen as the proper one.

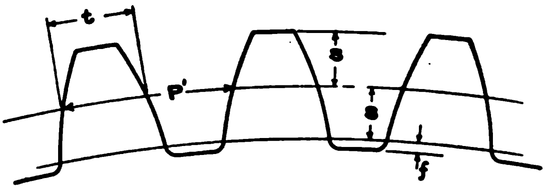
As stated under "Analysis," there are a great many circumstances attending the operation of gears which make impossible the purely theoretical application of the beam formulæ. For this reason there is no one element of machinery which depends so much on experience and judgment for correct proportion as the tooth of a gear. Hence it is true that a rational formula based on the theoretical one is really of the greater practical value in tooth design.

If we examine formula 61, we find that in a form solved for W, we have:

$$W = \frac{SFH^2}{6\,L}. \qquad (62)$$

Of these quantities, H and L are the only variables, for we can make the others what we choose. H and L depend upon the circular pitch P^1 and the curvature and outline of the tooth. If now we could settle on a standard system of teeth, we could establish a coefficient to be used to take the place of the variable part of H and L, which depends on the outline of tooth, and we should thus have an empirical formula which would be on a theoretical basis.

This, Mr. Wilfred Lewis has done; and it is safe to say that this formula is more universally used and with more satisfactory practical results than any other formula, theoretical or practical, that has ever been devised. His coefficient is known as y, and was determined from many actual drawings of different forms of teeth showing the weakest section. This coefficient is worked out for the three most common systems as follows:



$$t = \frac{P^1}{2}$$
$$f = \frac{t}{10}$$
$$s = \frac{P^1}{\pi}$$

Fig. 35.

For 20° involute, $$y = 0.154 - \frac{0.912}{N}. \qquad (63)$$

For 15° involute and cycloidal, $$y = 0.124 - \frac{0.684}{N}. \qquad (64)$$

For radial flanks, $$y = 0.075 - \frac{0.276}{N}. \qquad (65)$$

The tooth upon which the above is based is the American standard or Brown & Sharpe tooth, for which the proportions are shown in Fig. 35.

The "Lewis" formula* is:

$$W = SP^1 Fy. \qquad (66)$$

A table indicating the value of S for different speeds follows:

Safe Working Stresses for Different Speeds.

Speed of teeth, ft. per min.	100	200	300	600	900	1200	1800	2400
Cast iron	8000	6000	4800	4000	3000	2400	2000	1700
Steel	20000	15000	12000	10000	7500	6000	5000	4300

---

*NOTE. of the Lewis formula will be found

A usual relation of F to P^1 is:

For cast teeth, $F = 2P^1$ to $3P^1$. **(66)**

For cut teeth, $F = 3P^1$ to $4P^1$. **(67)**

The usual method of handling these formulæ is as follows:

The pitch circles of the proposed gears are known or can be assumed; hence W can readily be figured, also the speed of the teeth, whence S can be read from the table. The desired relation of F to P^1 can be arbitrarily chosen, when P^1 and y become the only unknown quantities in the equation. A shrewd guess can be made for the number of teeth, and y calculated therefrom. Then solve the equation for P^1 which will undoubtedly be fractional. Choose the nearest even pitch, or, if it is desired to keep an even diametral pitch, the fractional pitch that will bring an even diametral pitch. Now, from this final and corrected pitch, and the diameter of the pitch circle, calculate the number of teeth N in the gear. Check the assumed value of y by this positive value of N.

Another good way of using this formula is to start with the pitch and face desired, and the diameter of the pitch circle. In this case W is the only unknown quantity, and when found can be compared with the load required to be carried. If too small, make another and successive calculations until the result approximates the required load.

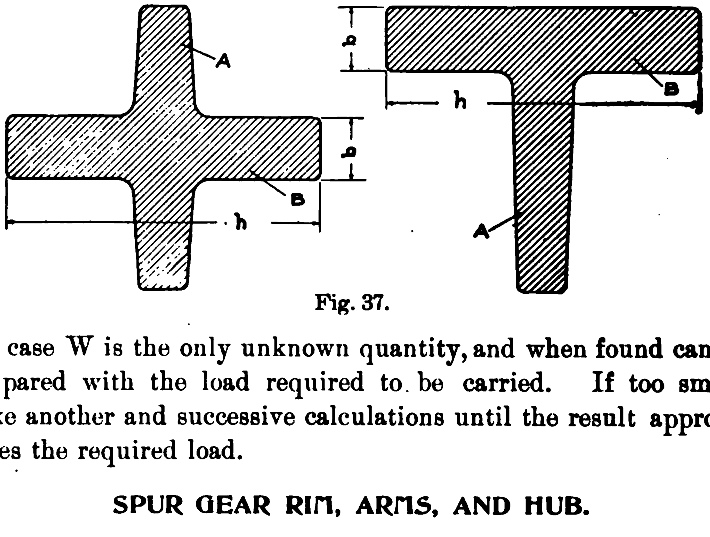


Fig. 37.

SPUR GEAR RIM, ARMS, AND HUB.

ANALYSIS and THEORY. The rim of a gear has to transmit the load on the teeth to the arms. It is thus in tension on one side of the teeth in action, and in compression on the other. The section of the rim, however, is so dependent on other practical considerations which call for an excess of strength in this respect, that it is not considered worth while to attempt a calculation on this basis.

Gears seldom run fast enough to make necessary a calculation for centrifugal force ; and in general it can be said that the design of the rim is entirely dependent on practical considerations. These will appear later under " Practical Modification."

The arms of a gear are stressed the same as pulley arms, the same theory answering for both, except that a gear rim always being much heavier than a pulley rim, the distribution of load amongst the arms is better in the case of a gear than of a pulley, and it is usually safe to assume that each arm of a gear takes its full proportion of load ; or, for an oval section, equating the external moment to the internal moment as in the case of pulleys, we have :

$$\frac{WD}{n2} = 0.0393\ Sh^3. \qquad (68)$$

Heavy spur gears have the arms of a cross or T section (Fig. 37), the latter being especially applicable to the case of bevel gears where there is considerable side thrust. The simplest way of treating such sections is to consider that the whole bending moment is taken by the rectangular section whose greater dimension is in the direction of the load. The rest of the section, being close to the neutral axis of the section, is of little value in resisting the direct load, its function being to give sidewise stiffness. The equation for the cross or T style of arm, then is :

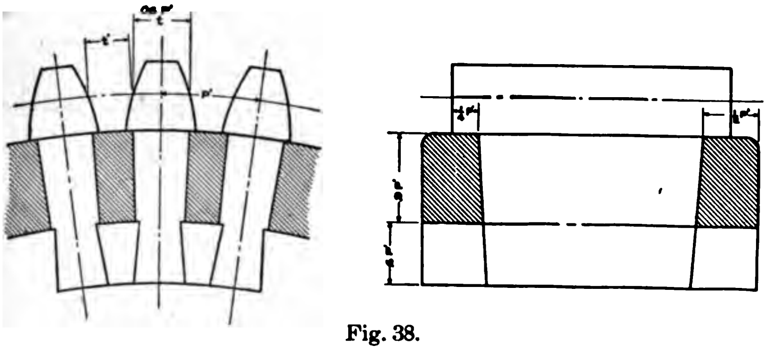


Fig. 38.

$$\frac{W}{n} \times \frac{D}{2} = \frac{Sbh^2}{6}. \qquad (69)$$

Either b or h may be assumed, and the other determined. As a guide to the section, b may be taken at about the thickness of the tooth.

Gear hubs are in no wise different from the hubs of pulleys or other rotating pieces. The depth necessary for providing sufficient strength over the key to avoid splitting is the guiding element, and can usually be best determined by careful judgment.

PRACTICAL MODIFICATION. The practical requirements, which no theory will satisfy, are many and varied. Sudden and severe shock, excessive wear due to an atmosphere of grit and corrosive elements, abrupt reversal of the mechanism, the throwing-in of clutches and pawls, the action of brakes—these and many other influences have an important bearing on gear design, but not one that can be calculated. The only method of procedure in such cases is to base the design on analysis and theory as previously given, and then add to the face of gear, thickness of tooth, or pitch an amount which judgment and experience dictate as sufficient.

Excessive noise and vibration are difficult to prevent at high speeds. At 1,000 feet per minute, gears are apt to run with an unpleasant amount of noise. At speeds beyond this, it is often necessary to provide **mortise teeth,** or teeth of hard wood set into a cast-iron rim (see Fig. 38). Rawhide pinions are useful in this regard. Fine pitches with a long face of tooth run much more smoothly at high speeds than a coarse pitch and narrow-faced tooth of equal strength. Greater care in alignment of shafts, however, is necessary, also stiffer supports.

Should it be impracticable to use a standard tooth of sufficient strength, there are several ways in which we can increase the carrying capacity without increasing the pitch. These are:

1. Use a stronger material, such as steel.
2. Shroud the teeth.
3. Use a hook tooth.
4. Use a stub tooth.

Shrouding a tooth consists in connecting the ends of the teeth with a rim of metal. When this rim is extended to the top of the tooth, the process is called "full-shrouding" (Fig. 39); and when carried only to the pitch line, it is termed "half-shrouding" (Fig. 40). The theoretical effect of shrouding is to make the tooth act like a short beam built in at the sides; and the tooth will practically have to be sheared out in order to fail. This modification of gear design requires the teeth to be cast, as the cutter cannot pass through the shrouding. The strength of the shrouded gear is estimated to be from 25 to 50 per cent above that of the plain-tooth type.

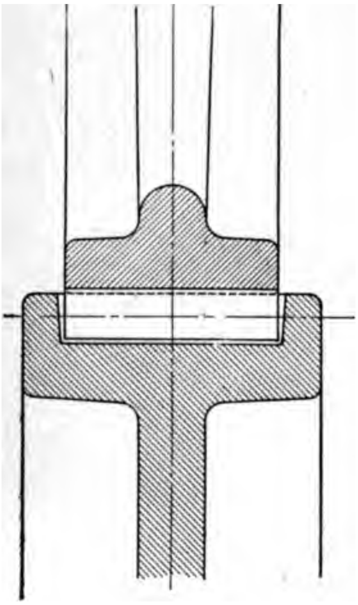


Fig. 39.

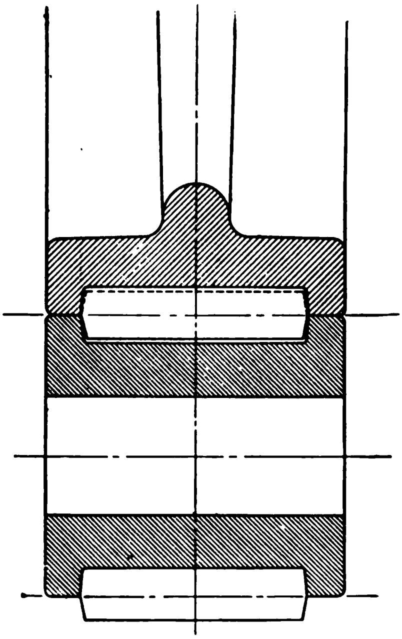


Fig. 40.

The **hook-tooth gear** (Fig. 41) is applicable only to cases where the load on the tooth does not reverse. The working side of the tooth is made of the usual standard curve, while the back is made of a curve of greater obliquity, resulting in a considerable increase of thickness at the root of the tooth. A comparison of strength between this form and the standard may be made by drawing the two teeth for a given pitch, measuring their thickness just at top of the fillet, and finding the relation of the squares of these dimensions. The truth of this relation is readily seen from an inspection of formula 61.

The **stub tooth** merely involves the shortening of the height of the tooth in order to reduce the lever arm on which the load acts, thus reducing the moment, and thereby permitting a greater load to be carried for the same stress.

The rim of a gear is dependent for its proportions chiefly on questions of practical moulding and machining. It must bear a certain relation to the teeth and arms, so that, when it is cooling in the mould, serious shrinkage stresses will not be set up, forming pockets and cracks. Moreover, when under pressure of the cutter in the producing of the teeth, it must not chatter or spring. This condition is quite well attained in ordinary gears when the thickness of the rim below the base of the tooth is made about the same as the thickness of the tooth.

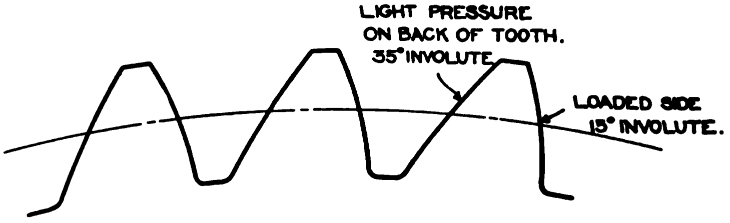


Fig. 41.

The stiffening ribs and arms must all be joined to the rim by ample fillets, and the cross-section must be as uniform as possible, to prevent unequal cooling and consequent pulling-away of the arms from the rim or hub. Often the calculated size of the arms at both rim and hub has to be modified considerably to meet this requirement.

The arms are usually tapered to suit the designer's eye, a small gear requiring more taper per foot than a large one. Both rim and hub should be tapered $\frac{1}{2}$ inch per foot to permit easy drawing-out from the mould.

The proportions given in the following table have been used with success as a basis of gear design in manufacturing practice. The table will serve as an excellent guide in laying out, and can be closely followed, in most cases with but slight modification. **Web gears** are introduced for small diameters where the arms begin to look awkward and clumsy.

Gear Design Data.

Measurements given in inches. Letters refer to Fig. 42.

Diametral pitch ..	P	1½	1¾	2	2½	3	3½	4	5	6	8
Face.............	F	6¼	5½	4¾	3¾	3¼	2¾	2½	2⅛	1⅞	1½
Thickness of arm when extended to pitch line....	G	1⅜	1¼	1⅛	1	⅞	13/16	¾	11/16	⅝	½
Width of arm when extended to pitch line	C	4	3½	3	2½	2¼	2	1¾	1½	1⅜	1⅛
Thickness of rim..	K	2¾	2⅜	2⅛	1¾	1½	1⅜	1¼	1	⅞	¾
Depth of rib......	E	2	1¾	1½	1¼	1	⅞	¾	⅝	½	⅜
Thickness of web.	T	1⅛	1	⅞	¾	⅝	9/16	½	7/16	⅜	5/16

Number of arms, 6.
Give inside of rims and hub a draft of ⅛ inch per foot.

BEVEL GEARS.

NOTATION—The following notation is used throughout the chapter on Bevel Gears:

A =Apex distance at pitch element of cone (inches).
A^1=Apex distance at bottom element of tooth (inches).
B =Angle of bottom of tooth (degrees).
C =Pitch angle (degrees).
D =Pitch diameter (inches).
E =Radius increment of gear (inches).
F =Face of gear (inches).
f =Clearance at bottom (inches).
G =Angle of face (degrees).
H =Cutting angle (degrees).
K =Radius increment of pinion (inches).
N =Number of teeth.
N^1=Formative number of teeth, or the number corresponding to the spur gear on which the outline of tooth is made.
O D=Outside diameter (inches).
P =Diametral pitch related to pitch diameter (teeth per inch).
P^1 =Circular pitch measured on the circumference of D (inches).
S =Working strength of material (lbs. per sq. in.).
s =Addendum, or height of tooth above pitch line (inches).
$s+f$=Depth of tooth below pitch line (inches).
T =Angle of top of tooth (degrees).
t =Thickness of tooth at pitch line (inches).
W =Working load at pitch line (lbs.).
y =Factor in "Lewis" formula.

ANA **ider bevel gears as the**
gen **form. The pitch**

surfaces of spur gears described above as cylinders, mathematically considered, are cones whose vertices are infinitely distant, while bevel gears likewise are based on pitch cones, but with a vertex at some finite point, common to the mating pair. Hence, as we might expect, the laws of tooth action are similar in bevel gears to those in the case of spur gears. The profile of the tooth in the former case, however, is based, not on the real radius of the pitch cone, but on the radius of the normal cone; and in the development of the outline the latter is treated just as though it were the radius of a spur gear. The tooth thus formed is wrapped back upon the normal cone face, and becomes the large end of the tapering bevel-gear tooth (see Fig. 44).

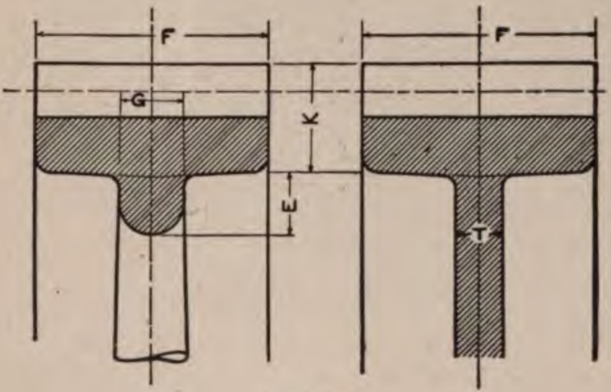


Fig. 42.

The teeth of bevel gears, being simply projections with bases on the pitch cones, have a varying cross-section decreasing toward the vertex; also a trapezoidal section of root, the latter section acting as a beam section to resist the cantilever moment due to the tooth load.

The arms must, as in the case of spur gears, transmit the load from the tooth to the shaft; in addition, the arms of a bevel gear are subjected to a side thrust due to the wedging action of the cones. Hence sidewise stiffness of the arms is more essential in this type of gear than in the case of the spur gear.

THEORY. It is evident that the calculation of tooth strength based on a trapezoidal section of root would be somewhat compli-

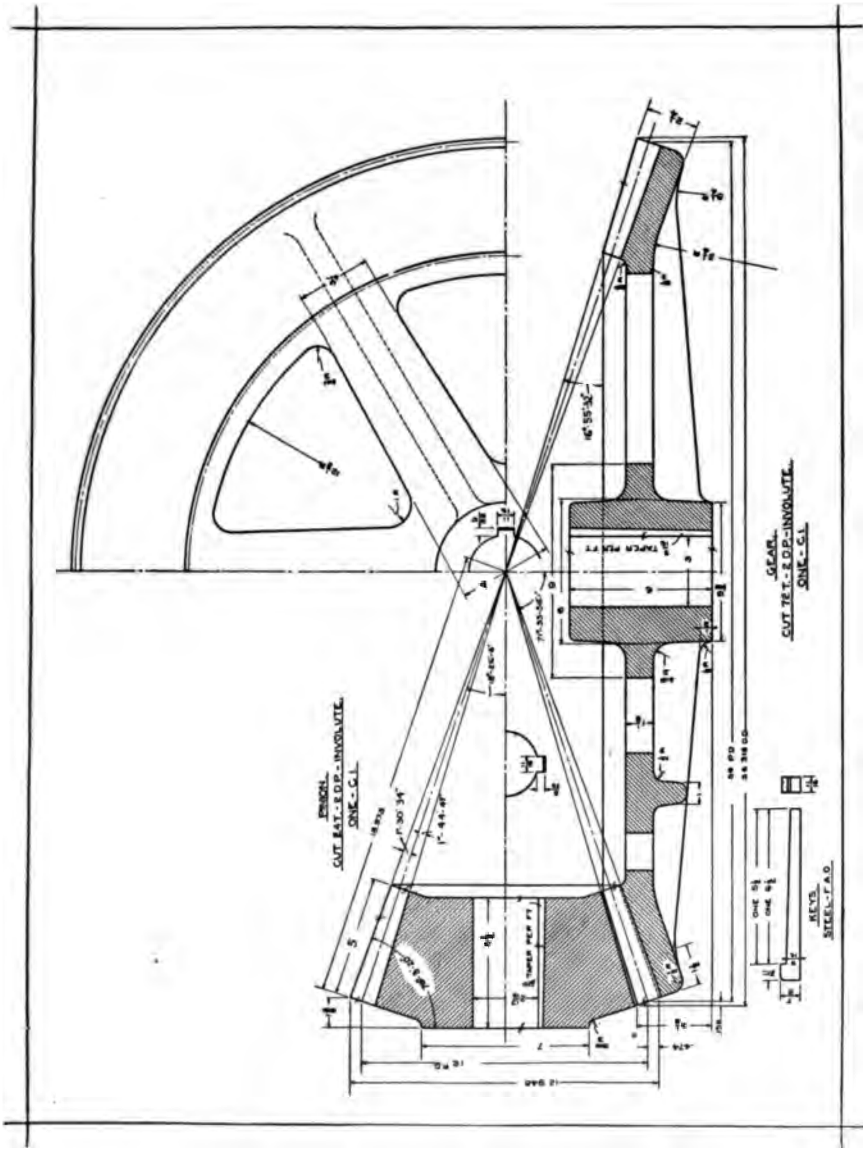
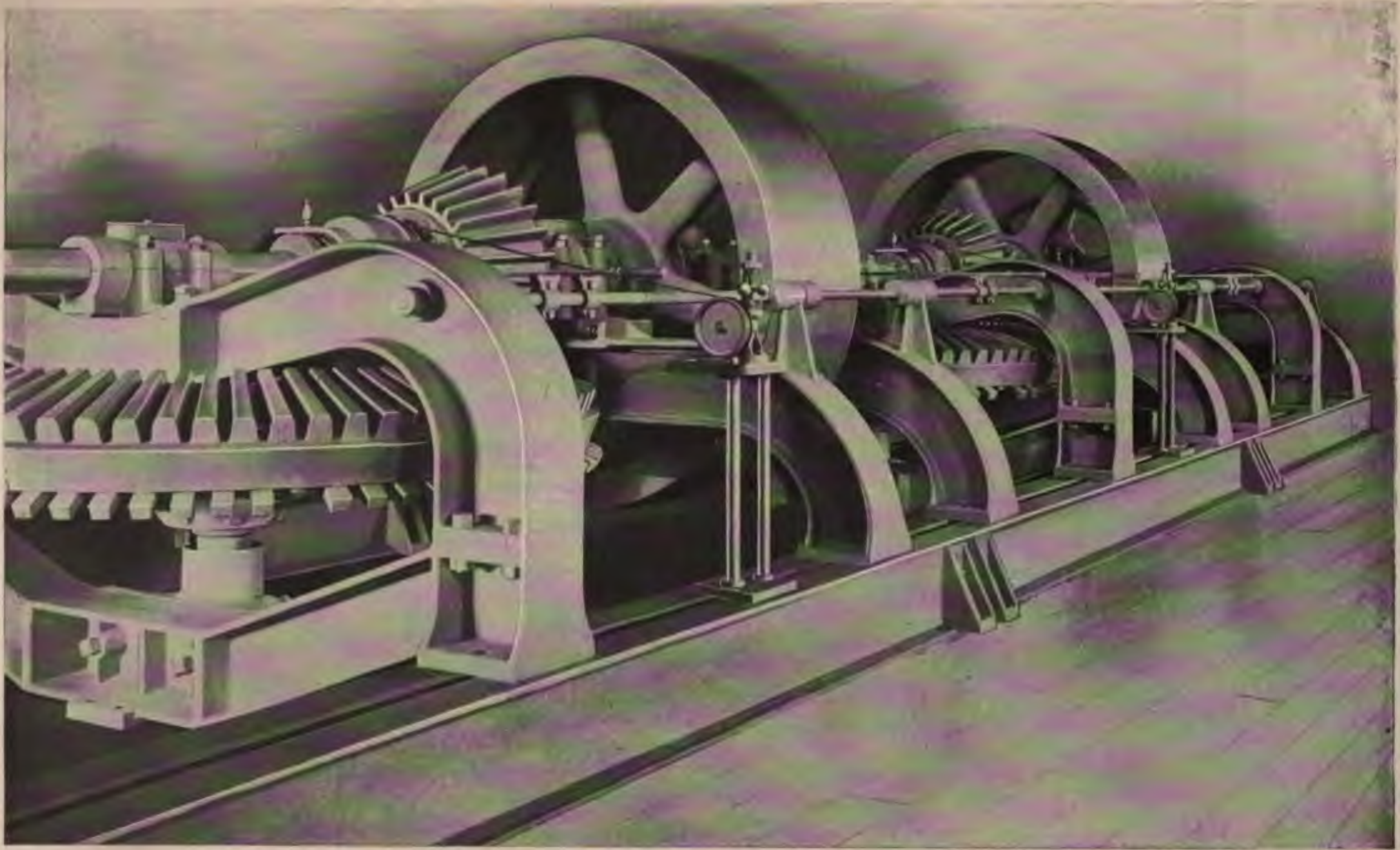


Fig. 43.

cated; also that the trapezoid in most cases would be but little different from a true rectangle. Hence the error will be but slight if the average cross-section of the tooth be taken to represent its strength, and the calculation made accordingly.



POWER CONNECTION INSTALLATION FOR HEAVY DUTY.

James Leffel and Company.

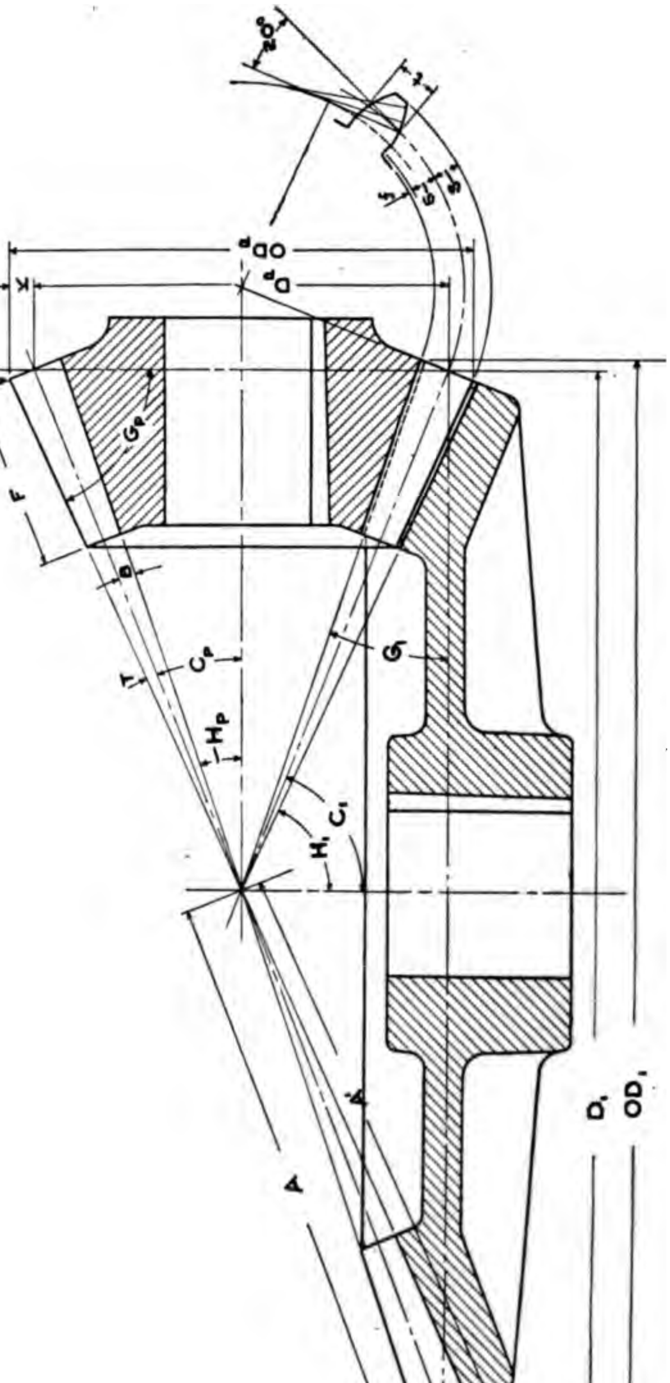


Fig. 44.

Fig. 45 shows a bevel-gear tooth with the average cross-section in dotted lines. For the purpose of calculation, the assumption is made that the section A is carried the full length of the face of the gear, and that the load which this average tooth must carry is the calculated load at the pitch line of section A. This is equivalent to saying that the strength of a bevel-gear tooth is equal to that of a spur-gear tooth which has the same face, and a section identical with that cut out by a plane at the middle of the bevel tooth. The load, as in the case of the spur gear, should be taken at the top of the tooth; and its magnitude can be conveniently calculated at the mean pitch radius of the bevel face, without appreciable error.

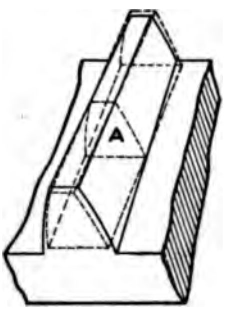


Fig. 45.

This similarity to spur gears being borne in mind, the calculation for strength needs no further treatment. Once the average tooth is assumed or found by layout, a strict following-out of the methods pursued for spur-gear teeth will bring consistent results.

The detail design of a pair of bevel gears involves some trigonometrical computations in order properly to dimension the drawing for use in finishing the blanks and subsequently in cutting the teeth, or, in the case of cast gears, in making the pattern. These calculations, although simple, are yet apt to be tedious; and inaccuracies are likely to creep in if a definite system of relations be not maintained. Hence the results of these calculations are given below in condensed and reduced form. The deduction of these formulæ is a simple and interesting exercise in trigonometry; and it is urged that they be worked out by the student from the figure, in which case he will feel greater confidence in their use.

Axes of Gears at 90 Degrees.

Use subscript 1 for gear; P for pinion. Letters refer to Fig. 44.

$$P = \frac{N}{D} = \frac{\pi}{P'}. \qquad (70)$$

$$s = \frac{1}{P} = \frac{P'}{\pi}. \qquad (71)$$

$$t = \frac{P'}{2} = \frac{\pi}{2P}. \qquad (72)$$

$$f = \frac{t}{10} = \frac{P^1}{20} = \frac{\pi}{20P}. \tag{73}$$

$$\tan C_p = \frac{N_p}{N_1};\ \tan C_1 = \frac{N_1}{N_p}. \tag{74}$$

$$\tan T = \frac{s}{A} = \frac{2 \sin C}{N}. \tag{75}$$

$$\tan B = \frac{s+f}{A} = \frac{2.314 \sin C}{N}. \tag{76}$$

$$s + f = A \tan B = \frac{1.157}{P} = 0.368P^1. \tag{77}$$

$$A = \frac{N}{2P \sin C} = \frac{1}{2P} \sqrt{N_1^2 + N_p^2} = \frac{1}{2} \sqrt{D_1^2 + D_p^2}. \tag{78}$$

$$A^1 = \frac{A}{\cos B} = \frac{N}{2P \cos B \sin C}. \tag{79}$$

$$G_1 = 90^\circ - (C_1 + T);\ G_p = 90^\circ - (C_p + T). \tag{80}$$

$$E = S \cos C_1 = S \sin C_p. \tag{81}$$

$$K = S \cos C_p = S \sin C_1. \tag{82}$$

PRACTICAL MODIFICATION. The practical requirements to be met in transmission of power by bevel gears are the same as for spur gears; but in the case of bevel gears even greater care is necessary to provide stiffness, strength, true alignment, and rigid supports. As far as the gears themselves are concerned, a long face is desirable; but it is much more difficult to gain the advantage of its strength than in the case of spur gears, because full bearing along the length of the tooth is hard to guarantee.

The rim usually requires a series of ribs running to the hub to give required stiffness and strength against the side thrust which is always present in a pair of bevel gears. Instead of arms, the tendency of bevel-gear design, except for very large gears, is toward a web on account of the better and more uniform connection thereby secured between rim and hub. This web may be lightened by a number of holes, so that the resultant effect is that of a number of wide and flat arms.

The hubs naturally have to be fully as long as those of spur gears, because there is greater tendency to rock on the shaft, due to the side thrust from the teeth, mentioned above.

The teeth on small gears are cut with rotary cutters, at least two finishing cuts being necessary, one for each side of the tapering tooth. The more accurate method is to plane the teeth on a special gear planer, and this method is followed on all gears of any considerable size. The practical requirement here is that no portion of the hub shall project so as to interfere with the stroke of the planer tool. The requirements of gear planers vary somewhat in this regard.

Finally, after all that is possible has been done in the design of the gear itself to render it suitable to withstand the varied stresses, especial attention must be paid to the rigidity of the supporting shafts and bearings. Bearings should always be close up to the hubs of the gears, and, if possible the bearing for both pinion and gear should be cast in the same piece. If this is not done, the tendency of the separate bearings to get out of line and destroy the full bearing of the teeth is difficult to control. Thrust washers are desirable against the hubs of both pinion and gear; also proper means of well lubricating the same.

With these considerations carefully met, bevel gears are not the bugbear of machine design that they are sometimes claimed to be. The common reason why bevel gears cut and fail to work smoothly, is that the gears and supports are not designed carefully enough in relation to each other. This is also true of spur gears, but the bevel gear will reveal imperfections in its design far the more quickly of the two.

WORM AND WORM GEAR.

NOTATION—The following notation is used throughout the chapter on Worm and Worm Gear:

D =Pitch diameter of gear (inches).
E =Efficiency between worm shaft and gear shaft (per cent).
f =Clearance of tooth at bottom (inches).
i =Index of worm thread (1 for single, 2 for double, etc.).
L =Lead of worm thread (inches).
M =Revolutions of gear shaft per minute.
M_w=Revolutions of worm shaft per minute.
N =Number of teeth in gear.
P^1 =Circular pitch = Pitch of worm thread (inches).
R =Radius of pitch circle of worm gear (inches).
s =Addendum of tooth (inches).
T =Twisting moment on gear shaft (inch-lbs.).
T_w=Twisting moment on worm shaft (inch-lbs.).
t =Thickness of tooth at pitch line (inches).
W =Load at pitch line (lbs.).

ANALYSIS. The simplest way of analyzing the case of the worm and worm gear is to base it upon an ordinary screw and nut. Take, for example, the lead screw of a common lathe. iage carries a nut, through which the lead screw passes. ation of the screw, the carriage, being constrained by the lengthwise of the ways, is moved. This motion is, for a single-threaded screw, a distance per revolution equal to the lead of the screw.

Now, suppose that the carriage, instead of sliding along the ways, is compelled to turn about an axis at some point below the ways. Also, suppose the top of the nut to be cut off, and its length made endless by wrapping it around a circle struck from the center about which the carriage rotates. This reduces the nut to a peculiar kind of spur gear, the partial threads of the nut now having the appearance of twisted teeth.

This special form of spur gear, based on the idea of a threaded nut, is known as a **worm gear**, and the screw is termed a **worm.** The teeth are loaded similarly to those of a spur gear, but with the additional feature of a large amount of sliding along the tooth surfaces. This, of course, means considerable friction; and it is in fact possible to utilize the worm and worm gear as an efficient device, only by running the teeth constantly in a bath of oil. Even then the pressures have to be kept well down to insure the required term of life of the tooth surfaces.

It is evident that for one revolution of a single-threaded worm, one tooth of the gear will be passed. The speed ratio between the worm gear and worm shaft will then be equal to the number of teeth in the gear, which is relatively great. Hence the worm and worm gear are principally useful in giving large speed reduction in a small amount of space.

THEORY. The theory of worm-wheel teeth is complicated and obscure. The production of the teeth is simple, a dummy worm with cutting edges, called a "hob," being allowed to carve its way into the worm-gear blank, thus producing the teeth and at the same time driving the worm gear about its axis.

It is clear that if we know the torsional moment on the worm-gear shaft, and the pitch radius of the worm gear, we can find the load on the teeth at the pitch line by dividing the former by the latter. Expressed as an equation:

$$WR = T; \text{or } W = \frac{T}{R}. \qquad (83)$$

How we shall consider this value of W as distributed on the teeth, is a question difficult to answer. The teeth not only are curved to embrace the worm, but are twisted across the face of the gear, so that it would be practically impossible to devise a purely theoretical method of exact calculation. The most reasonable thing to do is to assume the teeth as being equally as strong as spur-gear teeth of the same circular pitch, and to figure them accordingly. It is probably true, however, that the load is carried by more than one tooth, especially in a hobbed wheel; so we shall be safe in assuming that two—and, in case of large wheels, three—teeth divide the load between them. With these considerations borne in mind, the case reduces itself to that of a simple spur-gear tooth calculation, which has already been explained under the heading "Spur Gears."

The worm teeth, or threads, are probably always stronger than the worm-gear teeth; so no calculation for their strength need be made.

The twisting moment on the worm shaft is not determined so directly as in the case of spur gears. The relative number of revolutions of the two shafts depends upon the "lead" of the worm thread and the number of teeth in the gear.

Lead (L) is the distance parallel to the axis of the worm which any point in the thread advances in one revolution of the worm. **Pitch** (P^1) is the distance parallel to the axis of the worm between corresponding points on adjacent threads. The distinction between lead and pitch should be carefully observed, as the two are often confounded, one with the other.

The thread may be single, double, triple, etc., the index of the thread i, being 1, 2, 3, etc., in accordance therewith. The relation between lead and pitch may then be expressed by an equation, thus:

$$L = i\,P^1. \qquad (84)$$

When the index of the thread is changed the speed ratio is changed, the relation being shown by the equation:

$$\frac{M}{M_w} = \frac{i}{N} \qquad (85)$$

If the efficiency were 100 per cent between the two shafts, the twisting moments would be inversely as the ratio of the speeds thus:

$$\frac{T_w}{T} = \frac{M}{M_w} = \frac{i}{N};$$

or,
$$T_w = \frac{Ti}{N}; \tag{86}$$

but for an efficiency E the equation would be:

$$\frac{T_w}{T} = \frac{i}{EN};$$

or,
$$T_w = \frac{Ti}{EN}. \tag{87}$$

The diameter of the worm is arbitrary. Change of this diameter has no effect on the speed ratio. It has a slight effect on the efficiency, the smaller worm giving a little higher efficiency. The diameter of the worm runs ordinarily from 3 to 10 times the circular pitch, an average value being $4P^1$ or $5P^1$.

A longitudinal cross-section through the axis of the worm cuts out a rack tooth, and this tooth section is usually made of the standard 14½° involute form shown in Fig. 46 for a rack.

The end thrust, of a magnitude practically equal to the pressure between the teeth, has to be taken by the hub of the worm against the face of the shaft bearing. A serious loss of efficiency from friction is likely to occur here. This is often reduced, however, by roller or ball bearings. With two worms on the same shaft, each driving into a separate worm gear, it is possible to make one of the worms right-hand thread, and the other left-hand, in which case the thrust is self-contained in the shaft itself, and there is absolutely no end thrust against the face of the bearing. This involves a double outfit throughout, and is not always practicable.

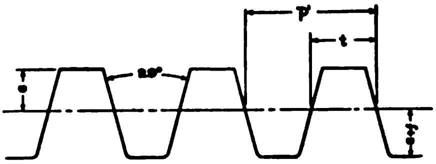


Fig. 46.

There are few mathematical equations necessary for the dimensioning of a worm and worm gear. The formulæ for the tooth parts as given on page 120 apply equally well in this case.

PRACTICAL MODIFICATION. The discussion of the efficiency E of the worm and worm gear is more of a practical than of a theoretical nature. It seems to be true from actual operation, as well as theory, that the steeper the threads the higher the efficiency. In actual practice we seldom have opportunity to change the slope of the thread to get increased efficiency. The slope is usually settled from considerations of speed ratio, or available space, or some other condition. The usual practical problem is to take a given worm and worm gear, and to make out of it as efficient a device as possible. With hobbed gears running in oil baths, and with moderate pressures and speeds, the efficiency will range between 40 per cent and 70 per cent. The latter figure is higher than is usually attained.

To avoid cutting and to secure high efficiency, it seems essential to make the worm and the gear of different materials. The worm-thread surfaces being in contact a greater number of times than the gear teeth, should evidently be of the harder material. Hence we usually find the worm of steel, and the gear of cast iron, brass, or bronze. To save the expense of a large and heavy bronze gear, it is common to make a cast-iron center and bolt a bronze rim to it.

The worm, being the most liable to replacement from wear, it is desirable so to arrange its shaft fastening and general accessibility that it may be readily removed without disturbing the worm gear.

The circular pitch of the gear and the pitch of the worm thread must be the same, and the practical question comes in as to the threads per inch possible to be cut in the lathe in the production of the worm thread. The pitch must satisfy this requirement; hence the pitch will usually be fractional, and the diameter of the worm gear, to give the necessary number of teeth, must be brought to it. While it would perhaps be desirable to keep an even diametral pitch for the worm gear, yet it would be poor design to specify a worm thread which could not be cut in a lathe.

The standard involute of 14½°, and the standard proportions of teeth as given on page 120, are usually used for worm threads. This system requires the gear to have at least 30 teeth, for if fewer teeth are used the thread of the worm will interfere with the flanks of the gear teeth. This is a mathematical relation, and there are methods of preventing it by change of tooth proportions or of angle of worm thread ; but there are few instances in which less than 30 teeth are required, and it is not deemed worth while to go into a lengthy discussion of this point.

The angle of the worm embraced by the worm-gear teeth varies from 60° to 90°, and the general dimensions of rim are made about the same as for spur gears. The arms, or the web, have the same reasons for their size and shape. Probably web gears and cross-shaped arms are more common than oval or elliptical sections.

Worm gears sometimes have cast teeth, but they are for the roughest service only, and give but a point bearing at the middle of the tooth. An accurately hobbed worm gear will give a bearing clear across the face of the tooth, and, if properly set up and cared for, makes a good mechanical device although admittedly of somewhat low efficiency.

Fig. 47 shows a detail drawing of a standard worm and worm gear. It should serve as a suggestion in design, and an illustration of the shop dimensions required for its production.

PROBLEMS ON SPUR, BEVEL, AND WORM GEARS.

1. Calculate proportions of a standard Brown & Sharpe gear tooth of 1$\frac{1}{2}$ diametral pitch, making a rough sketch and putting the dimensions on it.

2. Suppose the above tooth to be loaded at the top with 5,000 lbs. If the face be 6 inches, calculate the fiber stress at the pitch line, due to bending.

3. A tooth load of 1,200 lbs. is transmitted between two spur gears of 12-inch and 30-inch diameter, the latter gear making 100 revolutions per minute. Calculate a suitable pitch and face of tooth by the "Lewis" formula.

4. Assuming a $\frac{1}{2}$-inch web on the 12-inch gear, calculate the shearing fiber stress at the outside of a hub 4 inches in diameter

5. Design elliptical arms for the 30-inch gear, allowing $S = 2{,}200$.

6. Design cross-shaped arms for 30-inch gear.

7. Calculate the dimensions shown in formulæ 70 to 82 in- for a pair of bevel gears of 20 and 60 teeth respectively, 2 al pitch, and 4-inch face. (The use of logarithmic tables he calculation much easier than with the natural functions.)

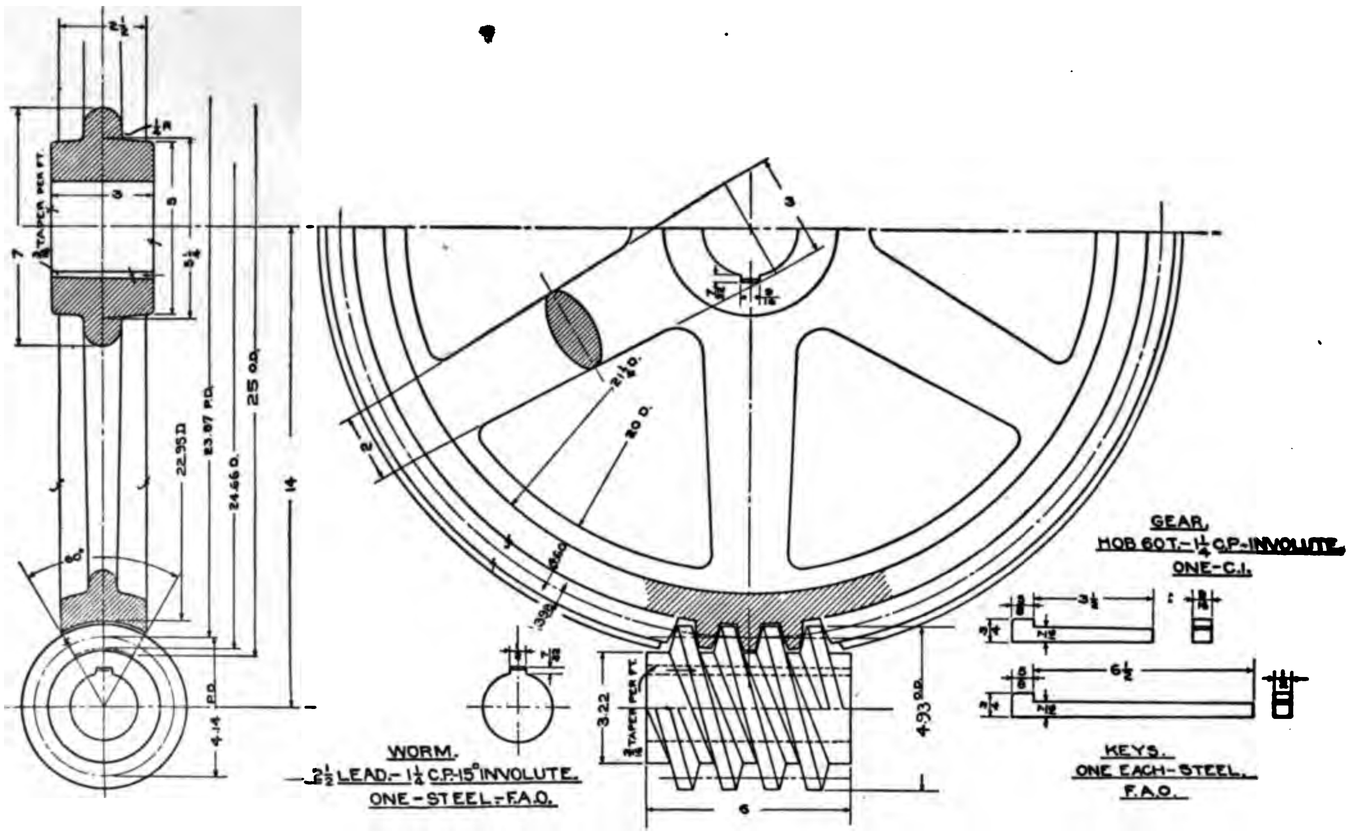

2½
¼R
⅜ TAPER PER FT.
3
5
7
5¼
22.95 D.
23.87 P.D.
24.66 D.
25 O.D.
14
60°
4.14 P.D.
3
2
2½ D.
20 D.
.660
.398
7/32
5/16
3.22
⅜ TAPER PER FT.
6
4.93 O.D.
WORM.
2½ LEAD.-1¼ C.P.-15° INVOLUTE.
ONE-STEEL.-F.A.O.
GEAR.
HOB 60 T.-1¼ C.P.-INVOLUTE.
ONE-C.I.
3½
6½
KEYS.
ONE EACH-STEEL.
F.A.O.

Fig. 47.

8. A worm wheel has 40 teeth, 3 diametral pitch, and double thread. Calculate (*a*) its lead; (*b*) its pitch diameter.

FRICTION CLUTCHES.

NOTATION—The following notation is used throughout the chapter on Friction Clutches:.

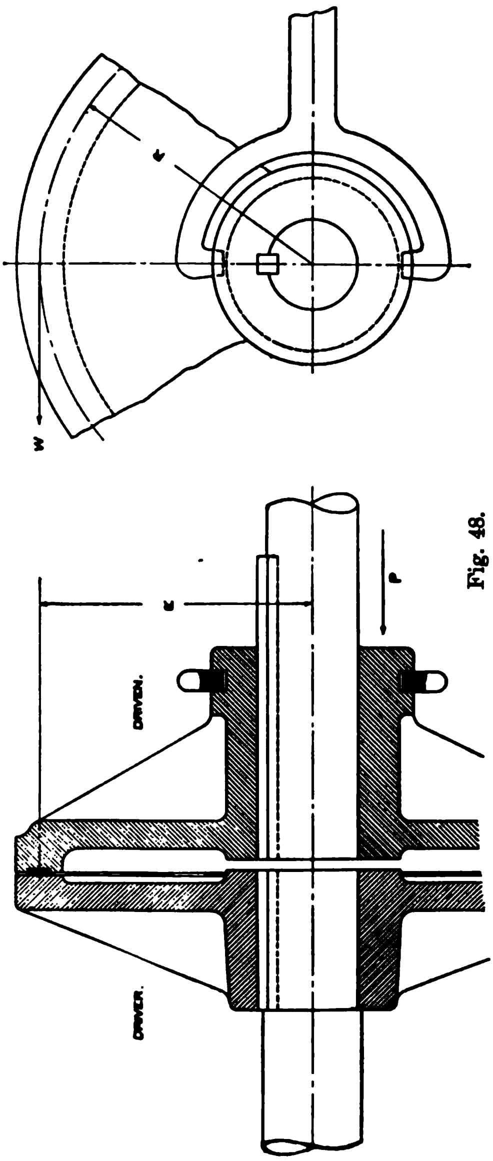


Fig. 48.

a =Angle between clutch face and axis of shaft (degrees)
H =Horse-power (33,000 ft.-lbs. per minute).
μ =Coefficient of friction (per cent).
N =Number of revolutions per minute.
P =Force to hold clutch in gear to produce W (lbs.).
R =Mean radius of friction surface (inches).
T =Twisting moment about shaft axis (inch-lbs.).
V =Force normal to clutch face (lbs.).
W =Load at mean radius of friction surface (lbs.).

ANALYSIS. The friction clutch is a device for connecting at will two separate pieces of shaft, transmitting an amount of power between them to the capacity of the clutch. The connection is usually accomplished while the driving shaft is under full speed, the slipping between the surfaces which occurs during the throwing-in of the clutch, permitting the driven shaft to pick up the speed of the other gradually, without appreciable shock. The disconnection is made in the same manner, the amount of slipping which occurs depending on the suddenness with which the clutch is thrown out.

The force of friction is the sole driving element, hence the problem is to secure as large a force of friction as possible. But friction cannot be secured without a heavy normal pressure between surfaces having a high coefficient of friction between them. The many varieties of friction clutches which are on the market or designed for some special purpose, are all devices for accomplishing one and the same effect, *viz.*, the production of a heavy normal force or pressure between surfaces at such a radius from the driven axis, that the product of the force of friction thereby created and the radius shall equal the desired twisting moment about that axis.

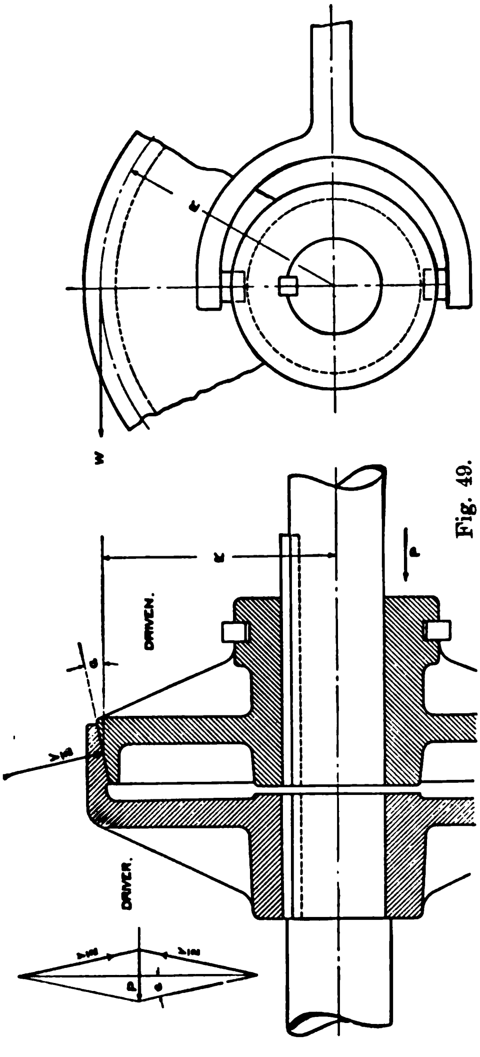


Fig. 49.

Three typical methods of accomplishing this are shown in Figs. 48, 49, and 50. None of these drawings is worked out in operative detail. They are merely illustrations of principle, and are drawn in the simplest form for that purpose.

In Fig. 48 the normal pressure is created in the simplest possible way, an absolutely direct push being exerted between the discs, due to the thrust P of the clutch fork.

In Fig. 49 advantage is taken of the wedge action of the inclined faces, the result being that it takes less thrust P to produce the required normal pressure at the radius R.

In Fig. 50 the inclination of the faces is carried so far that the angle *a* of Fig. 49 has become zero; and by the toggle-joint action of the link pivoted to the clutch collar, the normal force produced may be very great for a slight thrust P. By careful adjustment of the length of the link so that the jaw takes hold of the clutch surface, when the link stands nearly vertical, a very easy operating device is secured, and the thrust P is made a minimum.

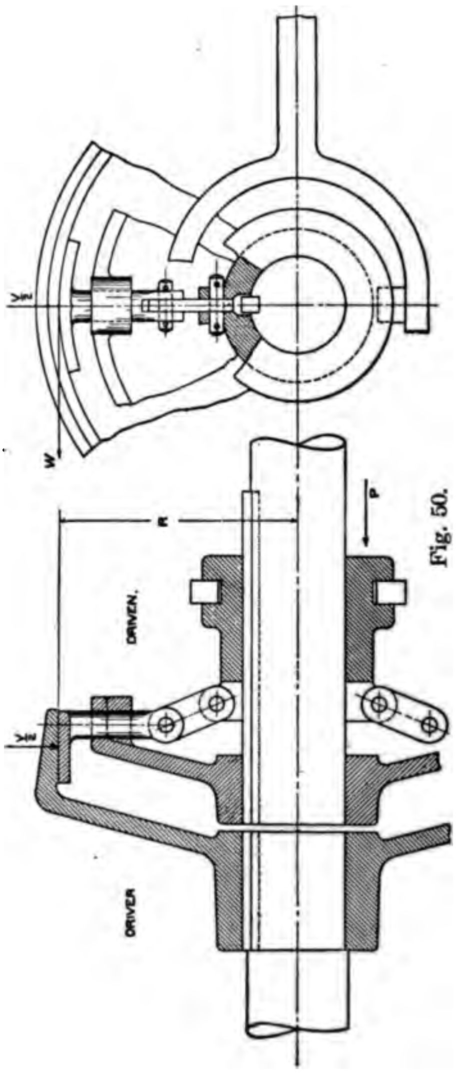


Fig. 50.

THEORY. Referring to Fig. 48 in order to calculate the twisting moment, we must remember that the force of friction between two surfaces is equal to the normal pressure times the coefficient of friction. This, in the form of an equation, using the symbols of the figure, is:

$$W = \mu P. \qquad (88)$$

Hence we may consider that we have a force of magnitude μP acting at the mean radius R of the clutch surface. The twisting moment will then be:

$$T = WR = \mu PR. \qquad (89)$$

Referring to equation 54, which gives twisting moment in terms of horse-power, and putting the two expressions equal to each other, we have:

$$T = \frac{63{,}025H}{N} = \mu PR;$$

or,

$$H = \frac{\mu NPR}{63{,}025}. \qquad (90)$$

This expression gives at once the horse-power that the clutch will transmit with a given end thrust P.

In Fig. 49 the equilibrium of the forces is shown in the little sketch at the left of the figure. The clutch faces are supposed to be in gear, and the extra force necessary to slide the two together is not considered, as it is of small importance. The static equations then are:

$$P = 2\frac{V}{2}\sin a;$$

or,

$$V = P \operatorname{cosec} a. \qquad (91)$$

$$W = \mu V = \mu P \operatorname{cosec} a. \qquad (92)$$

$$T = WR = \mu PR \operatorname{cosec} a. \qquad (93)$$

$$T = \frac{63{,}025H}{N} = \mu PR \operatorname{cosec} a;$$

or,

$$H = \frac{\mu NPR \operatorname{cosec} a}{63{,}025}. \qquad (94)$$

In Fig. 50, P would of course be variable, depending on the inclination of the little link. The amount of horse-power which this clutch would transmit would be the same as in the case of the device illustrated in Fig. 49, for an equal normal force V produced.

The further theoretical design of such clutches should be in accordance with the same principles as for arms and webs of pulleys, gears, [illegible] must be liberal in order to prevent tipping on the shaft as a result of uneven wear. The end thrust is apt to be considerable; and extra side stiffness must be provided, as well as a rim that will not spring under the radial pressure.

PRACTICAL MODIFICATION. It is desirable to make the most complicated part of a friction clutch the driven part, for then the mechanism requiring the closest attention and adjustment may be brought to and kept at rest when no transmission of power is desired.

Simplicity is an important practical requirement in clutches. The wearing surfaces are subjected to severe usage; and it is essential that they be made not only strong in the first place, but also capable of being readily replaced when worn out, as they are sure to be after some service.

The form of clutch shown in Fig. 50 is the most efficient form of the three shown, although its commercial design is considerably different from that indicated. Usually the jaws grip both sides of the rim, pinching it between them. This relieves the clutch rim of the radial unbalanced thrust.

Adjusting screws must be provided for taking up the wear, and lock nuts for maintaining their position.

Theoretically, the rubbing surfaces should be of those materials whose coefficient of friction is the highest; but the practical question of wear comes in, and hence we usually find both surfaces of metal, cast iron being most common. For metal on metal the coefficient of friction μ cannot be safely assumed at more than 15 per cent, because the surfaces are sure to get oily.

A leather facing on one of the surfaces gives good results as to coefficient of friction, μ having a value, even for oily leather, of 20 per cent. Much slipping, however, is apt to burn the leather; and this is most likely to occur at high speeds.

Wood on cast iron gives a little higher coefficient of friction for an oily surface than metal on metal. Wood blocks can be so set into the face of the jaws as to be readily replaced when worn, and in such case make an excellent facing.

The angle a of a cone friction clutch of the type shown in Fig. 49, may evidently be made so small that the two parts will wedge together tightly with a very slight pressure P; or it may

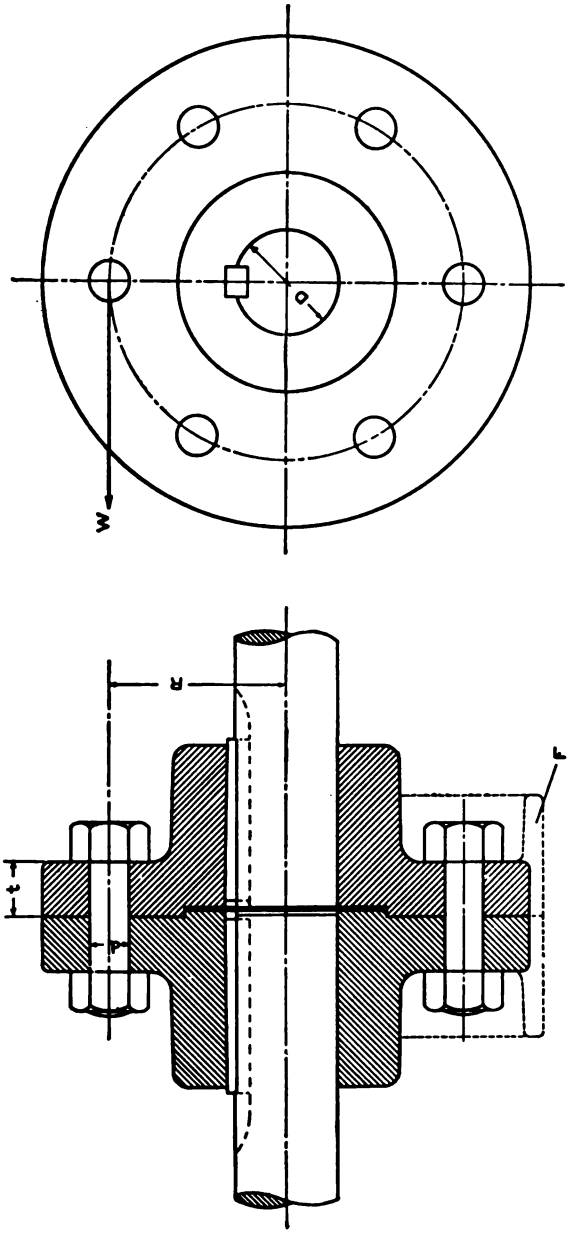
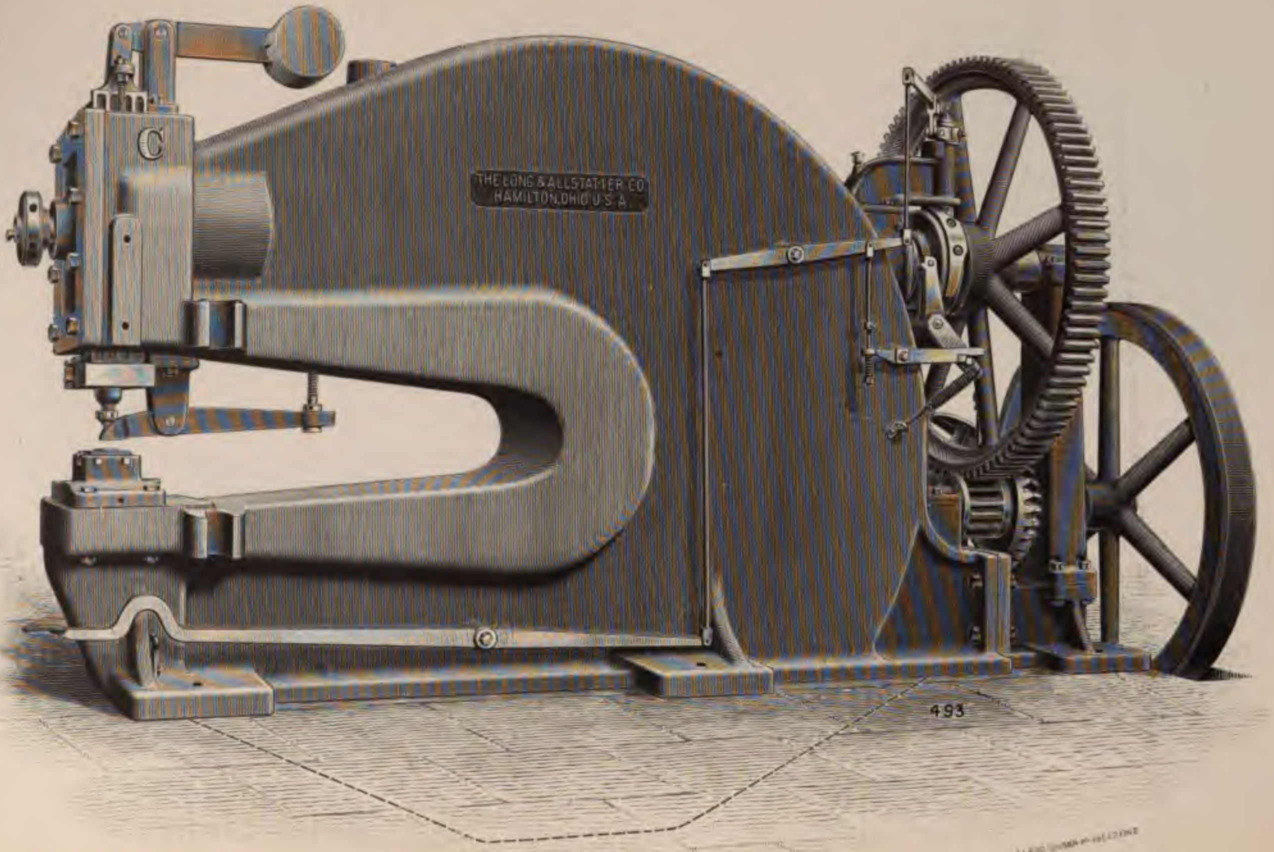


Fig. 51.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SINGLE PUNCHING OR SHEARING MACHINE.
Capacity 4½-inch hole in 1-inch plate.

be so large as to have little wedging action, and approach the condition illustrated in Fig. 48. Between these limits there is a practical value which neither gives a wedging action so great as to make the surfaces difficult to pull apart, nor, on the other hand, requires an objectionable end thrust along the shaft in order to make the clutch drive properly.

For a = about 15°, the surfaces will free themselves when P is relieved.
" a = " 12°, " " require slight pull to be freed.
" a = " 10°, " " cannot be freed by direct pull of the hand, but require some leverage to produce the necessary force P.

PROBLEMS ON FRICTION CLUTCHES.

1. With what force must we hold a friction clutch in to transmit 30 horse-power at 200 revolutions per minute, assuming working radius of clutch to be 12 inches; coefficient of friction 15 per cent; angle $a = 10°$?

2. How much horse-power could be transmitted, other conditions remaining the same, if the working radius were increased to 18 inches ?

3. What force would be necessary in problem 1, if the angle a were 15°, other conditions remaining the same ?

COUPLINGS.

NOTATION.—The following notation is used throughout the chapter on Couplings:

D = Diameter of shaft (inches).
d = Diameter of bolt body (inches).
n = Number of bolts.
R = Radius of bolt circle (inches).
S = Safe shearing fiber stress (lbs. per sq. in.).
S_c = Safe crushing fiber stress (lbs. per sq. in.).
T = Twisting moment (inch-lbs.).
t = Thickness of flange (inches).
W = Load on bolts (lbs.).

ANALYSIS. Rigid couplings are intended to make the shafts which they connect act as a solid, continuous shaft. In order that the shaft may be worked up to its full strength capacity, the coupling must be as strong in all respects as the shaft, or, in other words, it must transmit the same torsional moment. In the analysis of the forces which come upon these couplings, it is not considered that they are to take any side load, but that they are to act purely as torsional elements. It is doubtless true that in many cases they do have to provide some side strength and stiffness, but this is not their natural function, nor the one upon which their design is based.

Referring to Fig. 51, which is the type most convenient for analysis, we have an example of the simplest form of **flange coupling.** It consists merely of hubs keyed to the two portions, with flanges driving through shear on a series of bolts arranged concentrically about the shaft. The hubs, keys, and flanges are subject to the same conditions of design as the hubs, keys, and web of a gear or pulley, the key tending to shear and be crushed in the hub and shaft, and the hub tending to be torn or sheared from the flange. The driving bolts, which must be carefully fitted in reamed holes, are subject to a purely shearing stress over their full area at the joint, and at the same time tend to crush the metal in the flange, against which they bear, over their projected area. This latter stress is seldom of importance, the thickness of the flange, for practical reasons, being sufficient to make the crushing stress very low.

THEORY. The theory of hubs, keys, and flanges, being like that already given for pulleys and gears, need not be repeated for couplings. The shearing stress on the bolts is the only new point to be studied.

In Fig. 51, for a twisting moment on the shaft of T, the load at the bolt circle is $W = \frac{T}{R}$. If the number of bolts be n, equating the external force to the internal strength, we have:

$$W = \frac{T}{R} = \frac{S\pi d^2}{4} n. \qquad (95)$$

Although the crushing will seldom be of importance, yet for the sake of completeness its equation is given, thus:

$$W = \frac{T}{R} = S_c d t n. \qquad (96)$$

The internal moment of resistance of the shaft is $\frac{SD^3}{5.1}$; hence the equation representing full equality of strength between the shaft and the coupling, depending upon the shearing strength of the bolts, is:

$$\frac{SD^3}{5.1R} = \frac{S\pi d^2}{4} n. \qquad (97)$$

The theory of the other types of couplings is obscure, except as regards the proportions of the key, which are the same in all cases. The shell of the clamp coupling, Fig. 52, should be thick enough to give equal torsional strength with the shaft; but the exact function which the bolts perform is difficult to determine. In general the bolts clamp the coupling tightly on the shaft and provide rigidity, but the key does the principal amount of the driving. The bolt sizes, in these couplings, are based on judgment and relation to surrounding parts, rather than on theory.

PRACTICAL MODIFICATION. All couplings must be made with care and nicely fitted, for their tendency, otherwise, is to spring the shafts out of line. In the case of the flange coupling, the two halves may be keyed in place on the shafts, the latter then swung on centers in the lathe, and the joint faced off. Thus the joint will be true to the axis of the shaft; and, when it is clamped in position by the bolts, no springing out of line can take place.

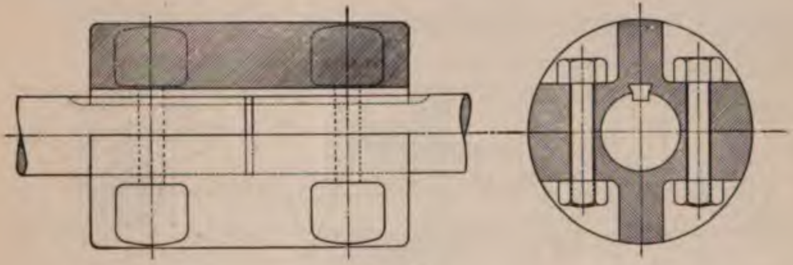


Fig. 52.

A flange F (see Fig. 51) is sometimes made on this form of coupling, in order to guard the bolts. It may be used, also, to take a light belt for driving machinery; but a side load is thereby thrown on the shaft at the joint, which is at the very point where it is desirable to avoid it.

The simplest form of rigid coupling consists of a plain sleeve slipped over from one shaft to the other, when the second is butted up against the first. This is known as a **muff coupling.** When once in place, this is a very excellent coupling, as it is perfectly smooth on the outside, and consists of the fewest possible parts, merely a sleeve and a key. It is, however, expensive to fit, difficult to remove, and requires an extra space of half its length on the shaft over which to be slipped back.

The **clamp coupling** is a good coupling for moderate-sized shafts, where the flange type of Fig. 51 would be unnecessarily expensive. The clamp coupling, Fig. 52, is simply a muff coupling split in halves, and recessed for bolts. It is cheap and is easily applied and removed, even with a crowded shaft. If bored with a piece of paper in the joint, when it is clamped in position it will pinch the shaft tightly and make a rigid connection. It is desirable to have the bolt-heads protected as much as possible, and this may be accomplished by making the outside diameter large enough so that the bolts will not project. Often an additional shell is provided to encase the coupling completely after it is located.

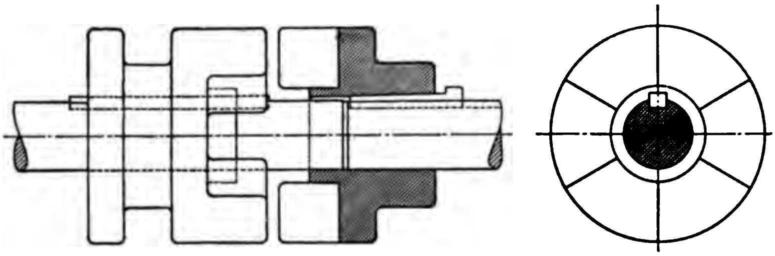


Fig. 53.

There are many other special forms of couplings, some of them adjustable. Most of them depend upon a wedging action exerted by taper cones, screws, or keys. Trade catalogues are to be sought for their description.

The **claw coupling,** Fig. 53, is nothing but a heavy flange coupling with interlocking claws or jaws on the faces of the flanges, to take the place of the driving bolts. This coupling can be thrown in or out as desired, although it usually performs the service of a rigid coupling, as it is not suited to clutching-in during rapid motion, like a friction clutch.

Flexible couplings, which allow slight lack of alignment, are made by introducing between the flanges of a coupling a flexible disc, the one flange being fastened to the inner circle of the disc, the other to the outer circle. This is also accomplished by providing the faces of the flange coupling with pins that drive by pressure together or through leather straps wrapped round the pins. These devices are mostly of a special and often uncertain nature, lacking the positiveness which is one essential feature of a good coupling.

PROBLEMS ON COUPLINGS.

1. A flange coupling of the type of Fig. 51 is used on a shaft 2 inches in diameter. The hub is 3 inches long, and carries a standard key, of proportions indicated below in the table of "Proportions for Gib Keys" (page 166). The bolt circle is 7 inches in diameter, and it is desired to use $\frac{5}{8}$-inch bolts. How many bolts are needed to transmit 60,000 inch-lbs., for a fiber stress in the bolt of 6,000 ?

2. Using 6 bolts, what diameter of bolt would be required ?

3. If four $\frac{3}{4}$-inch bolts were used on a circle of 8 inches diameter, what diameter of shaft would be used in the coupling to give equal strength with the bolts ?

BOLTS, STUDS, NUTS, AND SCREWS.

NOTATION—The following notation is used throughout the chapter on Bolts, Studs, Nuts, and Screws:

d = Diameter of bolt (inches).
d_1 = Diameter at root of thread (inches).
H = Height of nut (inches).
I = Initial axial tension (lbs.).
k = Allowable bearing pressure on surface of thread (lbs. per sq. in.).
L = Lead, or distance nut advances along axis in one revolution (inches).
l = Length of wrench handle (inches)
n = Number of threads in nut $= \frac{H}{p}$.
P = Axial load (lbs.).
p = Pitch of thread, or distance between similar points on adjacent threads, measured parallel to axis (inches).
S = Fiber stress (lbs. per sq. in.).
W = Load on bolt (lbs.).

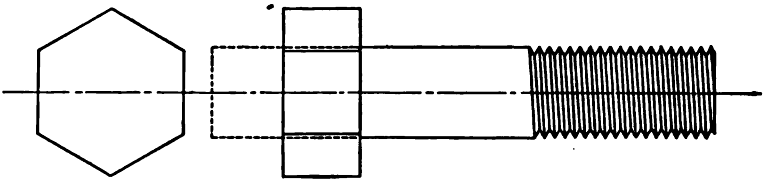


Fig. 54.

ANALYSIS. A **bolt** is simply a cylindrical bar of metal upset at one end to form a head, and having a thread at the other end, Fig. 54. A **stud** is a bolt in which the head is replaced by a thread; or it is a cylindrical bar threaded at both ends, usually having a small plain portion in the middle, Fig. 55. The object of bolts and studs is to clamp machine parts together, and yet permit these same parts to be readily disconnected. The bolt passes through the pieces to be connected, and, when tightened, causes surface compression between the parts, while the reactions on the head and nut produce tension in the bolt. Studs and tap bolts pass through one of the connected parts and are screwed into the other, the stud remaining in position when the parts are disconnected.

As all materials are elastic within certain limits, the action of a bolt in clamping two machine parts together, more especially if there is an elastic packing between them, may be represented diagrammatically by Fig. 56, in which a spring has been introduced to take the compression due to screwing up the nut. Evidently the tension in the bolt is equal to the force necessary to compress the spring. Now, suppose that two weights, each equal to $\frac{1}{2}$ W, are placed symmetrically on either side of the bolt, then the tension in the bolt will be increased by the added weights if the bolt is perfectly rigid. The bolt, however, stretches; hence some of the compression on the spring is relieved and the total tension in the

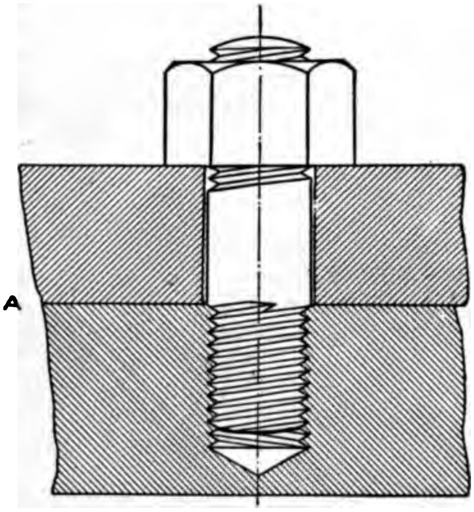


Fig. 55.

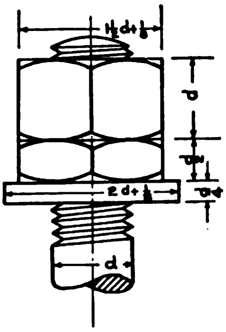


Fig. 55a.

bolt is less than W + I, by an amount depending on the relative elasticity of the bolt and spring.

Suppose that the stud in Fig. 55 is one of the studs connecting the cover to the cylinder of a steam engine, and that the studs have a small initial tension; then the pressure of the steam loads each stud, and, if the studs stretch enough to relieve the initial pressure between the two surfaces, then their stress is due to the steam pressure only; or, from Fig. 56, when I = W; the initial pressure due to the elasticity of the joint is entirely relieved by the assumed stretch of the studs. Except to prevent leakage, it is seldom necessary to consider the initial tension, for the stretch of the bolt may be counted on to relieve this force, and the working tension on the bolt is simply the load applied.

For shocks or blows, as in the case of the bolts found on the marine type of connecting-rod end, the stretch of the bolts acts like a spring to reduce the resulting tensions. So important is this feature that the body of the bolt is frequently turned down to the diameter of the bottom of the thread, thus uniformly distributing the stretch through the full length of the bolt, instead of localizing it at the threaded parts.

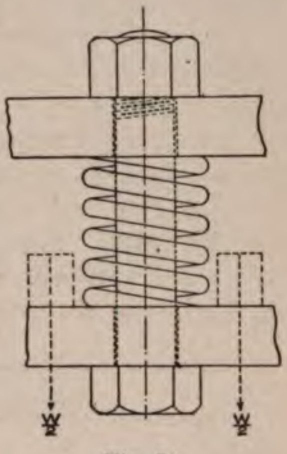


Fig. 56.

In tightening up a bolt, the friction at the surface of the thread produces a twisting moment, which increases the stress in the bolts, just as in the case of shafting under combined tension and torsion; but the increase is small in amount, and may readily be taken care of by permitting low values only for the fiber stress.

In a flange coupling, bolts are acted upon by forces perpendicular to the axis, and hence are under pure shearing stress. If the torque on the shaft becomes too great, failure will occur by the bolts shearing off at the joint of the coupling.

A bolt under tension communicates its load to the nut through the locking of the threads together. If the nut is thin, and the number of threads to take the load few, the threads may break or shear off at the root. With a V thread there is produced a component force, perpendicular to the axis of the bolt, which tends to split the nut.

In screws for continuous transmission of motion and power, the thread may be compared to a rough inclined plane, on which a small block, the nut, is being pushed upward by a force parallel to the base of the plane. The angle at the bottom of the plane is the angle of the helix, or an angle whose tangent is the lead divided by the circumference of the screw. The horizontal force corresponds to the tangential force on the screw. The friction at the surface of the thread produces a twisting moment about the axis of the screw, which, combined with the axial load, subjects the screw to combined tension and torsion. Screws with square threads are generally used for this service, the sides of the thread exerting no bursting pressure on the nut. The proportions of screw thread for transmission of power depend more on the bearing pressure than on strength. If the bearing surface be too small and lubrication poor, the screw will cut and wear rapidly.

THEORY. A direct tensile stress is induced in a bolt when it carries a load exerted along its axis. This load must be taken by the section of the bolt at the bottom of the thread. If the area at the root of the thread is $\frac{\pi d_1^2}{4}$, and if S is the allowable stress per square inch, then the internal resistance of the bolt is $\frac{S\pi d_1^2}{4}$. Equating the external load to the internal strength we have:

$$W = \frac{S\pi d_1^2}{4}. \qquad (98)$$

For bolts which are used to clamp two machine parts together so that they will not separate under the action of an applied load, the initial tension of the bolt must be at least equal to the applied load. If the applied load is W, then the parts are just about to separate when $I = W$. Therefore the above relation for strength is applicable. As the initial tension to prevent separation should be a little greater than W, a value of S should be chosen so that there will be a margin of safety. For ordinary wrought iron and steel, S may be taken at 6,000 to 8,000.

If, however, the joints must be such that there is no leakage between the surfaces, as in the case of a steam cylinder head, and supposing that elastic packings are placed in the joints, then a much larger margin should be made, for the maximum load which may come on the bolt is I + W, where W is the proportional share of the internal pressure carried by the bolt. In such cases S = 3,000 to 5,000, using the lower value for bolts of less than $\frac{3}{4}$-inch diameter.

The table given on page 154 will be found very useful in proportioning bolts with U. S. standard thread for any desired fiber stress.

To find the initial tension due to screwing up the nut, we may assume the length of the handle of an ordinary wrench, measured from the center of the bolt, as about 16 times the diameter of the bolt. For one turn of the wrench a force F at the handle would pass over a distance $2\pi l$, and the work done is equal to the product of the force and space, or F × $2\pi l$. At the same time the axial load P would be moved a distance p along the axis. Assuming that there is no friction, the equation for the equality of the work at the handle and at the screw is:

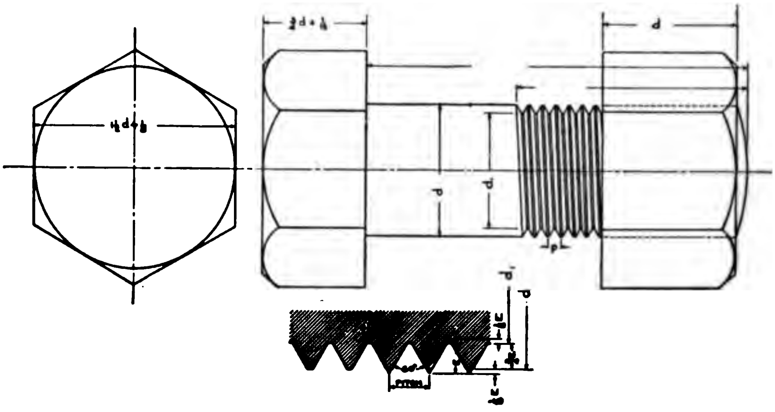


Fig. 56*a*.

$$F2\pi l = Pp. \qquad (99)$$

Friction, however, is always present; hence the ratio of the useful work (Pp) to the work applied ($F2\pi l$) is not unity as above re-

TABLE FOR STRENGTH OF BOLTS.—U. S. Standard Thread.

BOLT.		DIAMETERS.		AREAS.		APPROXIMATE TENSILE STRENGTH. AT BOTTOM OF THREAD. (IN HUNDREDS OF POUNDS.)					APPROXIMATE SHEARING STRENGTH. FULL BOLT DIAMETER. (IN HUNDREDS OF POUNDS.)			
Diameter. Inches.	Threads per inch.	Bottom of Thread.	Tap Drill.	Bolt Body.	Bottom of Thread.	At 4,000 lbs. per sq. in.	At 5,000 lbs. per sq. in.	At 6,000 lbs. per sq. in.	At 7,000 lbs. per sq. in.	At 10,000 lbs. per. sq. in.	At 4,000 lbs. per sq. in.	At 5,000 lbs. per sq. in.	At 6,000 lbs. per sq. in.	At 7,000 lbs. per sq. in.
¼	20	.18	3/16	.05	.03	1.08	1.35	1.60	1.88	2.69	1.96	2.45	2.95	3.43
5/16	18	.24	¼	.08	.04	1.82	2.27	2.73	3.18	4.54	3.04	3.83	4.60	5.37
⅜	16	.29	5/16	.11	.07	2.71	3.39	4.07	4.75	6.78	4.40	5.52	6.62	7.73
7/16	14	.34	23/64	.15	.09	3.73	4.67	5.60	6.53	9.33	6.00	7.51	9.02	11.00
½	13	.40	13/32	.20	.13	5.00	6.25	7.50	8.75	12.00	7.84	9.81	12.00	14
9/16	12	.45	15/32	.25	.16	6.48	8.10	9.62	11.00	16	9.92	12.00	15	17
⅝	11	.51	17/32	.31	.20	8.04	10.00	12.00	14	20	12.00	15	18	21
¾	10	.62	⅝	.44	.30	12.00	15	18	21	30	18	22	26	31
⅞	9	.73	¾	.60	.42	17	24	25	29	42	24	30	36	42
1	8	.84	27/32	.78	.55	22	27	33	38	55	31	39	47	55
1⅛	7	.94	31/32	.99	.69	28	34	41	48	69	40	50	60	70
1¼	7	1.06	1 3/32	1.23	.89	31	39	47	55	78	49	61	74	86
1⅜	6	1.16	1 3/16	1.48	1.05	42	53	64	72	106	59	74	89	104
1½	6	1.28	1 9/32	1.77	1.29	51	64	77	90	128	71	88	106	124
1⅝	5½	1.39	1 13/32	2.07	1.51	61	78	92	109	153	83	104	124	145
1¾	5	1.49	1½	2.40	1.74	70	88	106	123	176	96	120	144	168
1⅞	5	1.61	1⅝	2.76	2.06	81	101	122	142	203	110	138	166	193
2	4½	1.71	1¾	3.14	2.30	92	115	138	161	230	126	157	186	220
2¼	4½	1.96	1 31/32	3.98	3.02	125	156	187	218	312	159	199	238	278
2½	4	2.17	2 3/16	4.91	3.72	148	185	222	259	370	196	245	294	344
2¾	4	2.42	2 7/16	5.94	4.62	184	230	276	322	460	237	297	356	416
3	3½	2.63	2⅝	7.07	5.43	218	272	326	381	544	283	353	424	495
3¼	3½	2.88	2 29/32	8.29	6.51	264	330	396	462	660	332	415	498	581
3½	3¼	3.10	3 1/32	9.62	7.55	302	376	452	528	754	385	481	577	673
3¾	3	3.32	3 11/32	11.04	8.64	344	430	516	602	860	442	552	663	773
4	3	3.57	3 19/32	12.57	9.99	396	495	594	693	990	503	628	754	880
4¼	2⅞	3.80	3 13/16	14.19	11.33	452	565	678	791	1,130	567	709	851	993
4½	2¾	4.03	4 1/32	15.90	12.74	507	634	760	888	1,268	636	795	951	1,113
4¾	2⅝	4.25	4 9/32	17.72	14.22	567	709	851	1,993	1,420	709	886	1,063	1,240
5	2½	4.48	4½	19.63	15.76	630	788	946	1.103	1.676	785	982	1,178	1,374
5½	2⅜	4.95	4 31/32	23.76	19.27	770	962	1,154	1.347	1.924	950	1,188	1,425	1,663
6	2¼	5.42	5 7/16	28.27	23.09	923	1,159	1,384	1.617	2.307	1.128	1,414	1.696	1,979

lations assume. From numerous experiments on the friction of screws and nuts, it has been found that the efficiency may be as low as 10 per cent. Introducing the efficiency in above equation, it may be written:

$$\frac{Pp}{F2\pi l} = \frac{1}{10}. \qquad (100)$$

Assuming that 50 pounds is exerted by a workman in tightening up the nut on a 1-inch bolt, the equation above shows that P = 4,021 pounds; or the initial tension is somewhat less than the tabular safe load shown for a 1-inch bolt, with S assumed at 10,000 pounds per sq. inch.

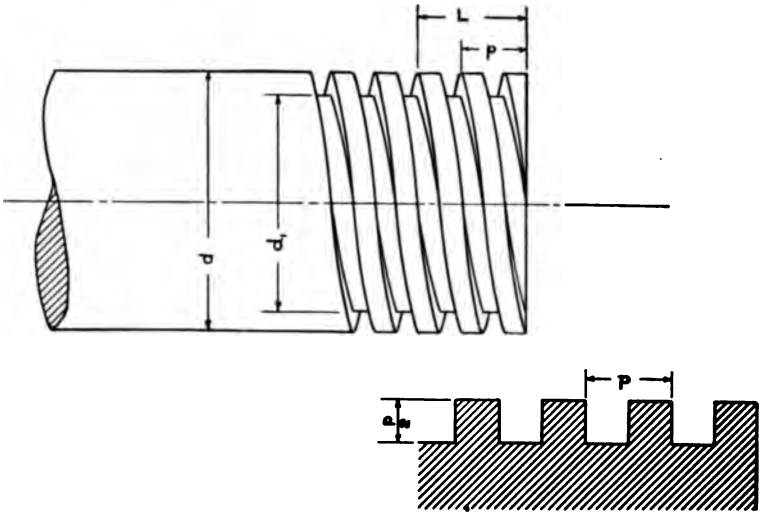


Fig. 58.

For shearing stresses the bolt should be fitted so that the body of the bolt, not the threads, resists the force tending to shear off the bolt perpendicular to its axis. The internal strength of the bolt to resist shear is the allowable stress S times the area of the bolt in shear, or $\frac{S\pi d^2}{4}$. If W represents the external force tending to shear the bolt the equality of the external force to the internal strength is:

$$W = \frac{S\pi d^2}{4}. \qquad (101)$$

TABLE FOR STRENGTH OF BOLTS.—U. S. Standard Thread.

Bolt.		Diameters.		Areas.		Approximate Tensile Strength. at Bottom of Thread. (In Hundreds of Pounds.)					Approximate Shearing Strength. Full Bolt Diameter. (In Hundreds of Pounds.)			
Diameter. Inches.	Threads per inch.	Bottom of Thread.	Tap Drill.	Bolt Body.	Bottom of Thread.	At 4,000 lbs. per sq. in.	At 5,000 lbs. per sq. in.	At 6,000 lbs. per sq. in.	At 7,000 lbs. per sq. in.	At 10,000 lbs. per sq. in.	At 4,000 lbs. per sq. in.	At 5,000 lbs. per sq. in.	At 6,000 lbs. per sq. in.	At 7,000 lbs. per sq. in.
1/4	20	.18	3/16	.05	.03	1.08	1.35	1.60	1.88	2.69	1.96	2.45	2.95	3.43
5/16	18	.24	1/4	.08	.04	1.82	2.27	2.72	3.18	4.54	3.04	3.83	4.60	5.37
3/8	16	.29	5/16	.11	.07	2.71	3.39	4.07	4.75	6.78	4.40	5.53	6.63	7.73
7/16	14	.34	11/32	.15	.09	3.73	4.67	5.60	6.53	9.83	6.00	7.51	9.02	11.00
1/2	13	.40	13/32	.20	.13	5.00	6.25	7.50	8.75	12.00	7.84	9.81	12.00	14
9/16	12	.45	15/32	.25	.16	6.48	8.10	9.62	11.00	16	9.92	12.00	15	17
5/8	11	.51	17/32	.31	.20	8.04	10.00	12.00	14	20	12.00	15	18	21
3/4	10	.62	5/8	.44	.30	12.00	15	18	21	30	18	22	26	31
7/8	9	.73	3/4	.60	.42	17	24	25	29	42	24	30	36	42
1	8	.84	27/32	.78	.55	22	27	33	38	55	31	39	47	55
1 1/8	7	.94	31/32	.99	.69	28	34	41	48	69	40	50	60	70
1 1/4	7	1.06	1 3/32	1.23	.89	31	39	47	55	78	49	61	74	86
1 3/8	6	1.16	1 3/16	1.48	1.05	43	53	64	73	106	59	74	89	104
1 1/2	6	1.28	1 9/32	1.77	1.29	51	64	77	90	128	71	88	106	124
1 5/8	5 1/2	1.39	1 13/32	2.07	1.51	61	78	92	109	153	83	104	124	145
1 3/4	5	1.49	1 1/2	2.40	1.74	70	88	106	123	176	96	120	144	168
1 7/8	5	1.61	1 5/8	2.76	2.05	81	101	123	142	203	110	138	166	193
2	4 1/2	1.71	1 3/4	3.14	2.30	92	115	138	161	230	126	157	186	220
2 1/4	4 1/2	1.96	1 31/32	3.98	3.02	125	156	187	218	313	159	199	238	278
2 1/2	4	2.17	2 3/16	4.91	3.72	148	185	222	259	370	196	245	294	344
2 3/4	4	2.42	2 7/16	5.94	4.62	184	230	276	322	460	237	297	356	416
3	3 1/2	2.63	2 5/8	7.07	5.43	218	272	326	381	544	283	353	424	495
3 1/4	3 1/2	2.88	2 29/32	8.29	6.51	264	330	396	462	660	332	415	498	581
3 1/2	3 1/4	3.10	3 3/32	9.62	7.55	302	376	452	528	754	385	481	577	673
3 3/4	3	3.32	3 11/32	11.04	8.64	344	430	516	602	860	443	552	663	773
4	3	3.57	3 19/32	12.57	9.99	396	495	594	693	990	503	628	754	880
4 1/4	2 7/8	3.80	3 13/16	14.19	11.33	452	565	678	791	1.180	567	709	851	998
4 1/2	2 3/4	4.03	4 1/32	15.90	12.74	507	634	760	888	1.268	636	795	951	1,113
4 3/4	2 5/8	4.25	4 9/32	17.72	14.22	567	709	851	1.993	1.420	709	886	1,068	1,240
5	2 1/2	4.48	4 1/2	19.63	15.76	630	788	946	1.103	1.676	785	982	1,178	1,374
5 1/2	2 3/8	4.95	4 31/32	23.76	19.27	770	963	1.154	1.347	1.924	950	1.188	1.425	1,663
6	2 1/4	5.42	5 7/16	28.27	23.09	923	1.150	1.384	1 617	2.307	1.128	1.414	1.696	1,979

Reference to the table on page 154 for the shearing strength of bolts, may be made to save the labor of calculations.

Let Fig. 58 represent a square thread screw for the transmission of motion. The surface on which the axial pressure bears, if n is the number of threads in the nut, is $\frac{\pi}{4}(d^2 - d_1^2)n$. Suppose that a pressure of k pounds per square inch is allowed on the surface of the thread. Then the greatest permissible axial load P must not exceed the allowable pressure; or, equating,

$$P = k\frac{\pi}{4}(d^2 - d_1^2)\,n. \qquad (102)$$

The value of k varies with the service required. If the motion be slow and the lubrication very good, k may be as high as 900. For rapid motion and doubtful lubrication, k may not be over 200. Between these two extremes the designer must use his judgment, remembering that the higher the speed the lower is the allowable bearing pressure.

PRACTICAL MODIFICATION. It will be noted in the formulæ for bolt strengths that different values for S are assumed. This is necessary on account of the uncertain initial stresses which are produced in setting up the nuts. For cases of mere fastening, the safe tension is high, as just before the joint opens the tension is about equal to the load and yet the fastening is secure. On the other hand, bolts or studs fastening joints subjected to internal fluid pressure must be stressed initially to a greater amount than the working pressure which is to come on the bolt. As this initial stress is a matter of judgment on the part of the workman, the designer, in order to be on the safe side, should specify not less than $\frac{5}{8}$-inch or $\frac{3}{4}$-inch bolts for ordinary work, so that the bolts may not be broken off by a careless workman accidentally putting a greater force than necessary on the wrench handle. In making a steam-tight joint, the spacing of the bolts will generally determine their number; hence we often find an excess of bolt strength in joints of this character.

Through bolts are preferred to studs, and studs to tap bolts or cap screws. If possible, the design should be such that through bolts may be used. They are cheapest, are always in standard stock, and well resist rough usage in connecting and disconnecting. The threads in cast iron are weak and have a tendency to crumble; and if a through bolt cannot be used in such a case, a stud, which can be placed in position once for all, should be employed—not a tap bolt, which injures the thread in the casting every time it is removed.

The plain portion of a stud should be screwed up tight against the shoulder, and the tapped hole should be deep enough to prevent bottoming. To avoid breaking off the stud at the shoulder, a neck, or groove, may be made at the lower end of the thread entering the nut.

To withstand shearing forces the bolts must be fitted so that no lost motion may occur, otherwise pure shearing will not be secured.

Nuts are generally made hexagonal, but for rough work are often made square. The hexagonal nut allows the wrench to turn through a smaller angle in tightening up, and is preferred to the square nut. Experiments and calculations show that the height of the nut with standard threads may be about ½ the diameter of the bolt and still have the shearing strength of the thread equal to the tensile strength of the bolt at the root of the thread. Practically, however, it is difficult to apply such a thin wrench as this proportion would call for on ordinary bolts. More commonly the height of the nut is made equal to the diameter of the bolt so that the length of thread will guide the nut on the bolt, give a low bearing pressure on the threads, and enable a suitable wrench to be easily applied. The standard proportions for bolts and nuts may be found in any handbook. Not all manufacturers conform to the United States standard; nor do manufacturers in all cases conform to one another in practice.

If the bolt is subject to vibration, the nuts have a tendency to loosen. A common method of preventing this is to use double nuts, or **lock nuts**, as they are called (see Fig. 55 A). The under nut is screwed tightly against the surface, and held by a wrench while the second nut is screwed down tightly against the first. The effect is to cause the threads of the upper nut to bear against the under sides of the threads of the bolt. The load on the bolt is sustained therefore by the upper nut, which should be the thicker of the two; but for convenience in applying wrenches the position of the nuts is often reversed.

The form of thread adapted to transmitting power is the square thread, which, although giving less bursting pressure on the nut, is not as strong as the V thread for a given length, since the total section of thread at the bottom is only ½ as great. If the pressure is to be transmitted in but one direction, the two types may be combined advantageously to form the buttress thread of the proportions shown in Fig. 59. Often, as in the carriage of a lathe, to allow the split nut to be opened and closed over the lead screw, the sides of the thread are placed at a small angle, say 15°, to each other, as illustrated in Fig. 60.

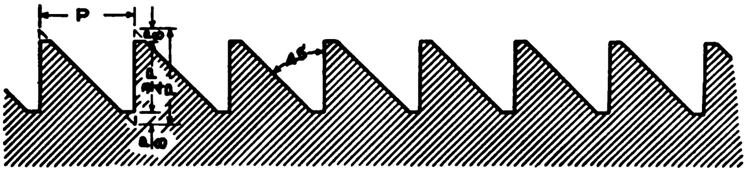


Fig. 59.

The practical commercial forms in which we find screwed fastenings are included in five classes, as follows:

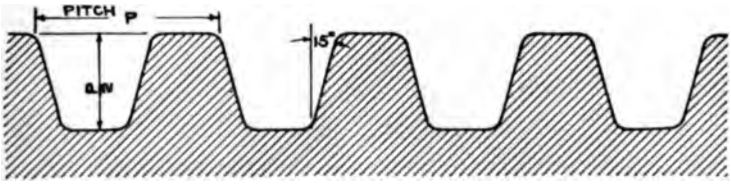


Fig. 60.

1. **Through bolts** (Fig. 61), usually rough stock, with square upset heads, and square or hexagonal nuts.

2. **Tap bolts** (Fig. 62), also called **cap screws.** These usually have hexagonal heads, and are found both in the rough form, and finished from the rolled hexagonal bar in the screw machine.

3. **Studs** (Fig. 63), rough or finished stock, threaded in the screw machine.

4. **Set screws** (Fig. 64), usually with square heads, and case-hardened points. Many varieties of set screws are made, the

principal distinguishing feature of each being in the shape of the point. Thus, in addition to the plain beveled point, we find the "cupped," rounded, conical, and "teat" points.

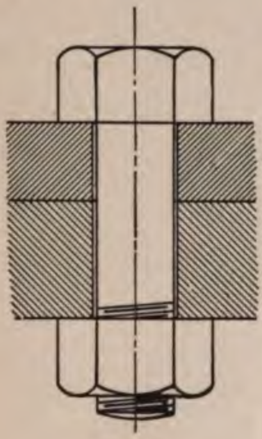


Fig. 61.

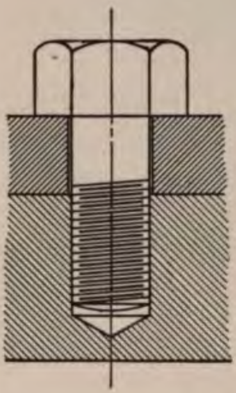


Fig. 62.

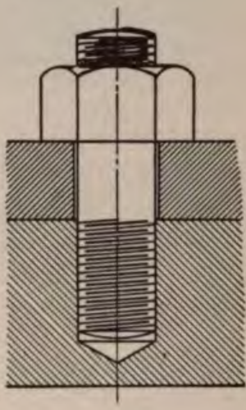


Fig. 63.

5. **Machine screws** (Fig. 64*a*), usually round, "button," or countersunk head. Common proportions are indicated relative to diameter of body of screw.

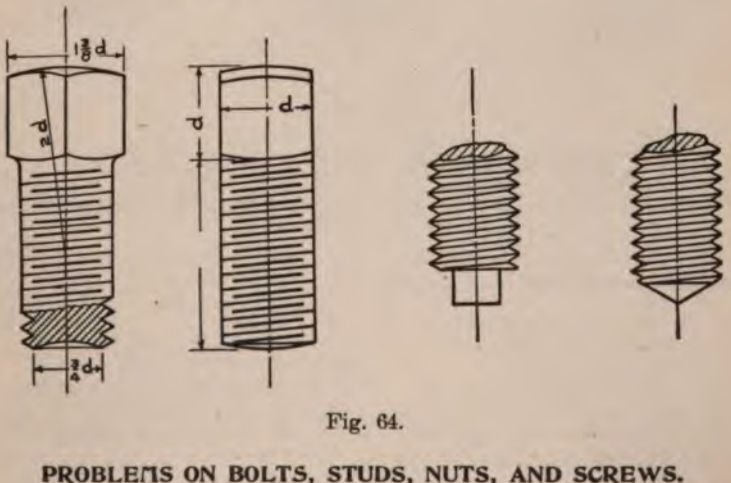


Fig. 64.

PROBLEMS ON BOLTS, STUDS, NUTS, AND SCREWS.

1. Calculate the diameter of a bolt to sustain a load of 5,000 lbs.

2. The shearing force to be resisted by each of the bolts of a flange coupling is 1,200 lbs. What commercial size of bolt is required?

3. With a wrench 16 times the diameter of the bolt, and an efficiency of 10 per cent, what axial load can a man exert on a standard $\frac{3}{4}$-inch bolt, if he pulls 40 lbs. at the end of the wrench handle?

4. A single, square-threaded screw of diameter 2 inches, lead $\frac{1}{4}$ inch, depth of thread $\frac{1}{8}$ inch, length of nut 3 inches, is to be allowed a bearing pressure of 300 lbs. per square inch. What axial load can be carried?

5. Calculate the shearing stress at the root of the thread in problem 4.

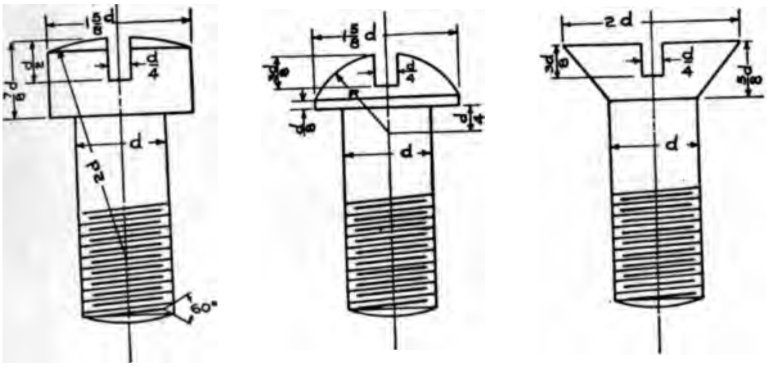


Fig. 64*a*.

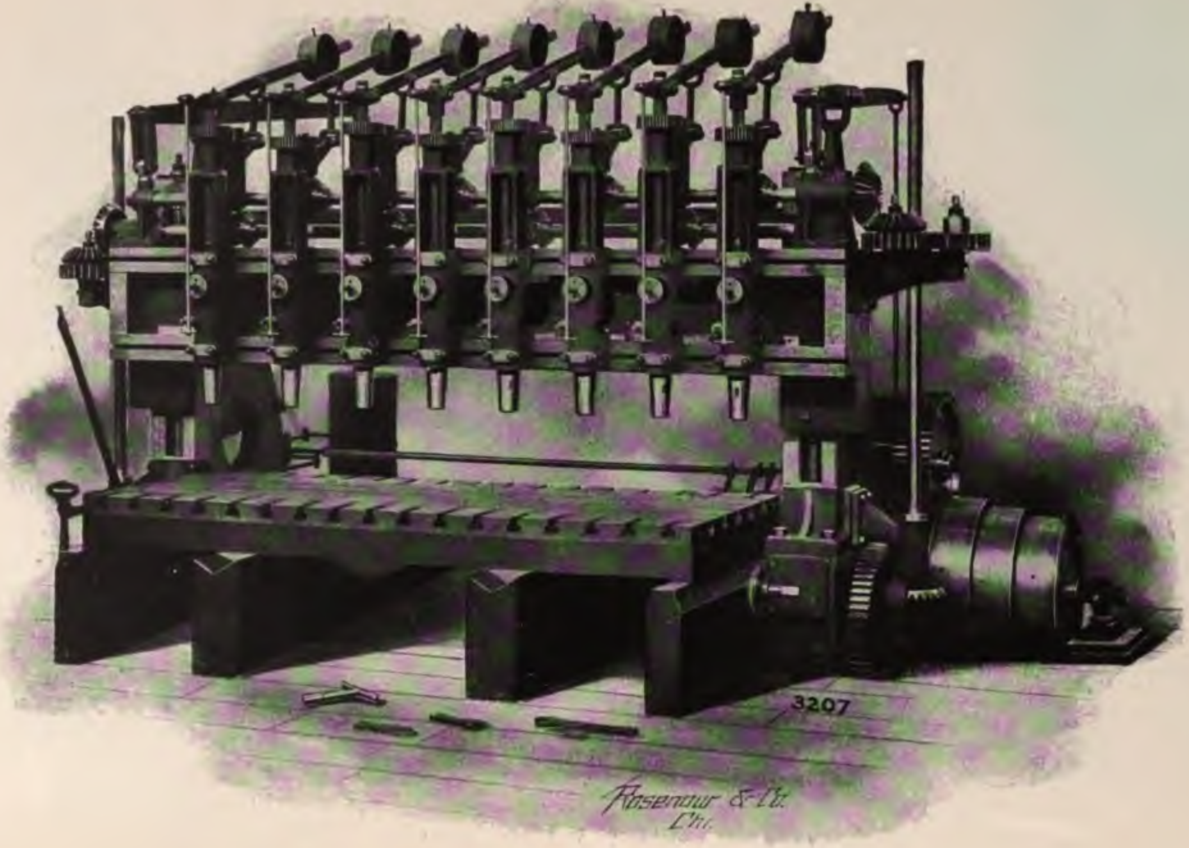
KEYS, PINS, AND COTTERS.

NOTATION—The following notation is used throughout the chapter on Keys, Pins, and Cotters:

D = Average diameter of rod (inches).
D_1 = Outside diameter of socket (inches).
d = Diameter of shaft (inches).
L = Length of key (inches).
P = Driving force (lbs.).
P_1 = Axial load on rod (lbs.).
R = Radius at which P acts (inches).
S_c = Safe crushing fiber stress (lbs. per sq. in.).
S_s = Safe shearing fiber stress (lbs. per sq. in.).
S_t = Safe tensile fiber stress (lbs. per sq. in.).
T = Thickness of key (inches).
W = Width of key (inches).
w = Average width of cotter (inches).
w_1 = End of slot to end of rod (inches).
w_2 = End of slot to end of socket (inches).

KEYS AND PINS.

ANALYSIS. Keys and pins are used to prevent relative



MULTIPLE DRILLING MACHINE.

Niles-Bement-Pond Co.

rotary motion between machine parts intended to act together as one piece. If we drill completely through a hub and across the shaft, and insert a tightly fitted pin, any rotary motion of the one will be transmitted to the other, provided the pin does not fail by shearing off at the joint between the shaft and the hub. The shearing area is the sum of the cross-sections of the pin at the joint.

We may drill a hole in the joint, the axis of the hole being parallel to the axis of the shaft, and drive in a pin, in which case we introduce a shearing area as before, but the area is now equal to the diameter of the pin multiplied by its length, and the pin is stressed sidewise, instead of across. It is evident in the sidewise case that we may increase the shearing area to anything we please, without changing the diameter of the pin, merely by increasing the length of the pin.

As there are some manufacturing reasons why a round pin placed lengthwise in the joint is not always applicable, we may make the pin a rectangular one, in which case it is called a **key.**

When pins are driven across the shaft as in the first instance, they are usually made taper. This is because it is easier to ream a taper hole to size than a straight hole, and a taper pin will drive more easily than a straight pin, it not being necessary to match the hole in hub and shaft so exactly in order that the pin may enter. The taper pin will draw the holes into line as it is driven, and can be backed out readily in removal.

Keys of the rectangular form are either straight or tapered, but for different reasons from those just stated for pins. Straight keys have working bearing only at the sides, driving purely by shear, crushing being exerted by the side of the key in both shaft and hub, over the area against the key. The key itself does not prevent end motion along the shaft; and if end motion is not desired, auxiliary means of some sort must be resorted to, as, for example, set screws through the hub jamming hard against the top of the key.

If end motion along the shaft is desired, the key is called a **spline,** and, while not jammed against the shaft, is yet prevented from changing its relation to the hub by some means such as illustrated in Fig. 65.

Taper keys not only drive through sidewise shearing strength, but prevent endwise motion by the wedging action exerted between the shaft and hub. These keys drive more like a strut from corner to corner; but this action is incidental rather than intentional, and the proportions of a taper key should be such that it will give its full resisting area in shearing and crushing, the same as a straight key.

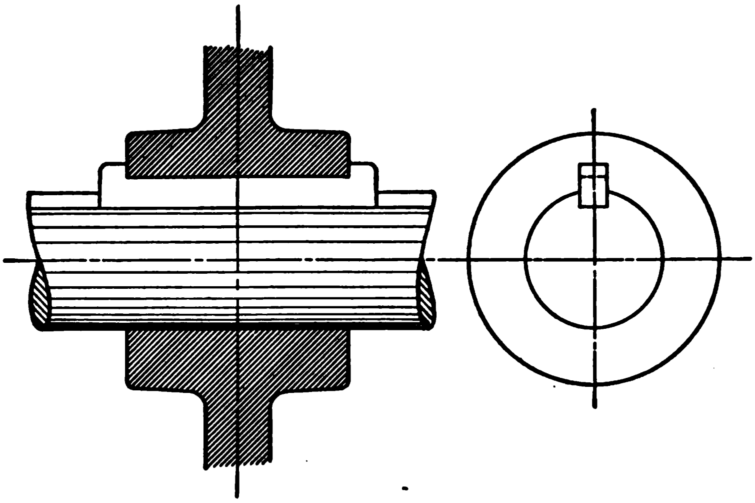


Fig. 65.

THEORY. Suppose that the pin illustrated in Fig. 66 passes through hub and shaft, and the driving force P acts at the radius R; then the force which is exerted at the surface of the shaft to shear off the pin at the points A and B is $\frac{2\,PR}{d}$. If D_1 is the average diameter of the pin, its shearing strength is $\frac{2\pi D_1^2 S_s}{4}$. Equating the external force to the internal strength, we have:

$$\frac{2PR}{d} = \frac{2\pi D_1^2 S_s}{4};$$

or,

$$D_1 = \sqrt{\frac{4PR}{\pi d S_s}}. \qquad (103)$$

In Fig. 67 a rectangular key is sunk half way in hub and shaft according to usual practice. Here the force at the surface of the shaft, calculated the same as before, not only tends to shear off the key along the line AB, but tends to crush both the portion in the shaft and in the hub. The shearing strength along the

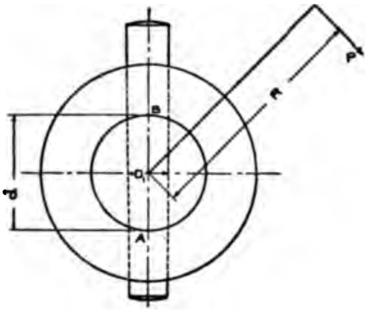


Fig. 66.

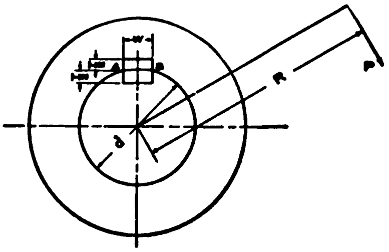


Fig. 67.

line AB is LWS_s. Equating external force to internal strength, we have:

$$\frac{2PR}{d} = LWS_s;$$

or,

$$W = \frac{2PR}{dLS_s}. \qquad (104)$$

The crushing strength is, of course, that due to the weaker metal, whether in shaft or hub. Let S_c be this least safe crushing fiber stress. The crushing strength then is $\frac{LT}{2}$ S_c, and, equating external force to internal strength, we have:

$$\frac{2PR}{d} = \frac{LT}{2} S_c;$$

or,

$$T = \frac{4PR}{dLS_c}. \qquad (105)$$

The proportions of the key must be such that the equations as above, both for shearing and for crushing, shall be satisfied.

PRACTICAL MODIFICATION. Pins across the shaft can be used to drive light work only, for the shearing area cannot be very large. A large pin cuts away too much area of the shaft, decreasing the latter's strength, Pins are useful in preventing end motion, but in this case are expected to take no shear, and may be of small diameter. The common split pin is especially adapted to this service, and is a standard commercial article.

Taper pins are usually listed according to the Morse standard taper, proportions of which may be found in any handbook. It is desirable to use *standard* taper pins in machine construction, as the reamers are a commercial article of accepted value, and readily obtainable in the machine-tool market.

With properly fitted keys, the shearing strength is usually the controlling element. For shafts of ordinary size, the standard proportions as given in tables like that below are safe enough without calculation, up to the limit of torsional strength of the shaft. For special cases of short hubs or heavy loads, a calculation is needed to check the size, and perhaps modify it.

Splines, also known as "feather keys," require thickness greater than regular keys, on account of the sliding at the sides. A table suggesting proportions for splines is given on page 166.

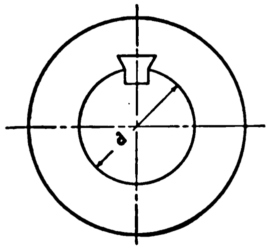


Fig. 67*a*.

Though the spline may be either in the shaft or hub, it is the more usual thing to find the spline dovetailed (Fig. 67*a*), "gibbed," or otherwise fastened in the hub; and a long spline way made in the shaft, in which it slides.

The straight key, accurately fitted, is the most desirable fastening device for accurate machines, such as machine tools, on account of the fact that there is absolutely no radial force exerted to throw the parts out of true. It, however, requires a tight fit of hub to shaft, as the key cannot be relied upon to take up any looseness.

The taper key (Fig. 68), by its wedging action, will take up some looseness, but in so doing throws the parts out slightly. Or, even if the bored fit be good, if the taper key be not driven home with care, it will spring the hub, and make the parts run untrue. The great advantage, however, that the taper key has of holding the hub from endwise motion, renders it a very useful and practical article. It is usually provided with a head, or "gib," which permits a draw hook to be used to wedge between the face
e key to facilitate starting the key from its seat.

Two keys at 90° from each other may be used in cases where one key will not suffice. The fine workmanship involved in spacing these keys so that they will drive equally makes this plan inadvisable except in case of positive and unavoidable necessity.

The "Woodruff" key (Fig. 69) is a useful patented article for certain locations. This key is a half-disc, sunk in the shaft and the hub is slipped over it. A simple rotary cutter is dropped into the shaft to produce the key seat; and on account of the depth in the shaft, the tendency to rock sidewise is eliminated, and the drive is purely by shear.

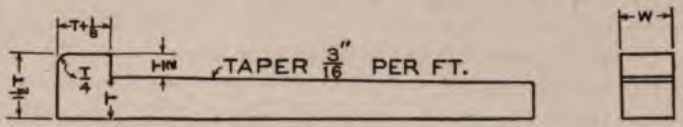


Fig. 68.

Keys may be milled out of solid stock, or drop-forged to within a small fraction of finished size. The drop-forged key is an excellent modern production and requires but a minimum amount of fitting. Any key, no matter how produced, requires some hand fitting and draw filing to bring it properly to its seat and give it full bearing.

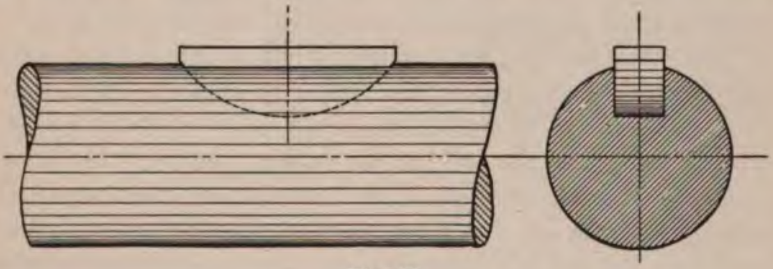


Fig. 69.

It is good mechanical policy to avoid keyed fastenings whenever possible. This does not mean that keys may never be used, but that a key is not an ideal way to produce an absolutely positive drive, partly because it is an expensive device, and partly because the tendency of any key is to work itself loose, even if carefully fitted.

The following tables are suggested as a guide to proportions of gib keys and feather keys, and will be found useful in the absence of any manufacturer's standard list:

Fig. 70. **PROPORTIONS FOR GIB KEYS.**

Diameter of shaft (d), inches.	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{5}{8}$	2	$2\frac{1}{2}$	$3\frac{1}{4}$	4	5	$6\frac{1}{2}$
Width (W), inches.	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{11}{16}$	$\frac{7}{8}$	$1\frac{1}{16}$	$1\frac{5}{16}$	$1\frac{5}{8}$
Thickness (T), inches.	$\frac{1}{4}$	$\frac{9}{32}$	$\frac{5}{16}$	$\frac{13}{32}$	$\frac{7}{16}$	$\frac{17}{32}$	$\frac{21}{32}$	$\frac{13}{16}$	1	$1\frac{1}{4}$

Fig. 71. **PROPORTIONS FOR FEATHER KEYS.**

Diameter of Shaft (d), inches,	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	$4\frac{1}{2}$
Width (W), inches.	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{5}{8}$
Thickness (T), inches.	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$

COTTERS.

ANALYSIS. Cotters are used to fasten hubs to rods rather than shafts, the distinction between a rod and a shaft being that a rod takes its load in the direction of its length, and does not drive by rotation. A cotter, therefore, is nothing but a cross-pin of modified form, to take shearing and crushing stress in the direction of the axis of the rod, instead of perpendicular to it.

Referring to Fig. 72, one will see that the cotter is made long and thin—long, in order to get sufficient shearing area to resist shearing along lines A and B; thin, in order to cut as little cross-sectional area out of the body of the shaft as possible. The cotter itself tends to shear along the lines A and B, and crush along the surfaces K, G, and J. The socket tends to crush along the surfaces K and G. The rod end D tends to be sheared out along the lines C H and Q E, and also to be crushed along the surface J. The socket tends to be sheared along the lines V U and X Y.

The cotter is made taper on one side, thus enabling it to draw up the flange of the rod tightly against the head of the socket. This taper must not be great enough to permit easy "backing out" and loosening of the cotter under load or vibration in the rod. In responsible situations this cannot be safely guarded against except through some auxiliary locking device, such as lock nuts on the end of the cotter (Fig. 73).

THEORY. Referring to Fig. 72, assume an axial load of P_1, as shown. The successive equations of external force to internal strength are enumerated below, for the different actions that take place:

For shearing along lines A and B, w being the average width of cotter, and S_s safe shearing stress of cotter,

$$P_1 = 2TwS_s. \qquad (106)$$

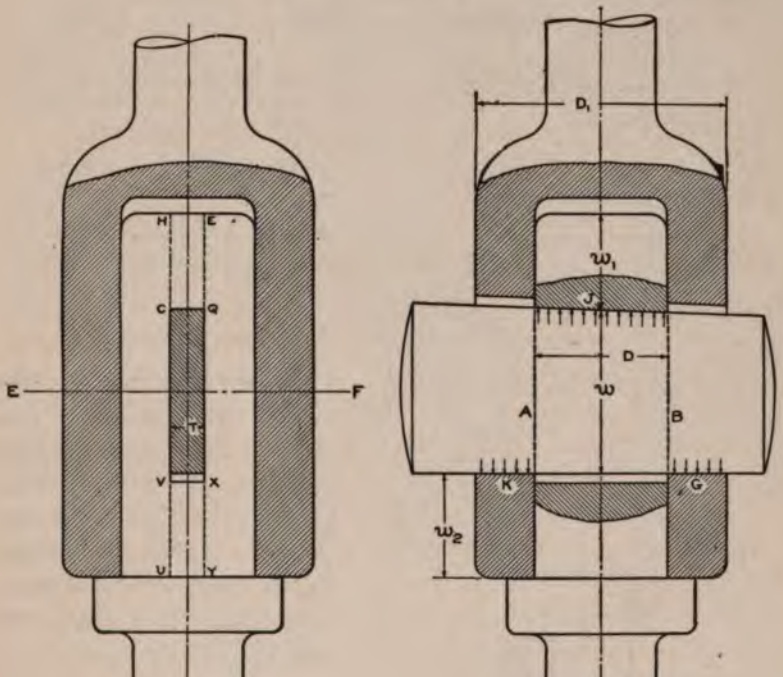


Fig. 72.

For crushing along surfaces K and G, S_c being least safe crushing stress, whether of cotter or socket,

$$P_1 = T(D_1 - D)S_c. \qquad (107)$$

For crushing along surface J, S_c being least safe crushing stress, whether of cotter or socket,

$$P_1 = DTS_c. \qquad (108)$$

For shearing along surfaces CH and QE, S_s being safe shearing stress of rod end, and w_1 end of slot to end of rod,

$$P_1 = 2w_1DS_s. \qquad (109)$$

For tension in rod end at section across slot, S_t being safe tensile stress in rod end,

$$P_1 = (\frac{\pi D^2}{4} - TD)S_t. \qquad (110)$$

For tension in socket at section across slot, S_t being safe tensile stress in socket,

$$P_1 = [\frac{\pi D_1^2}{4} - \frac{\pi D^2}{4} - T(D_1 - D)]S_t. \qquad (111)$$

For shearing in socket along the lines VU and XY, S_s being safe shearing stress in the socket, and w_2 end of slot to end of socket,

$$P_1 = 2w_2(D_1 - D)S_s. \qquad (112)$$

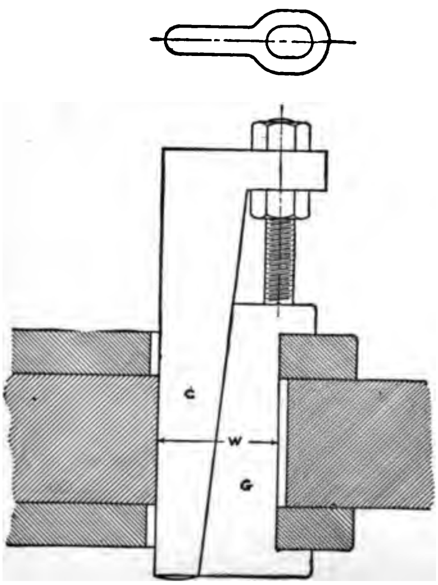


Fig. 73.

The proportions of cotter and socket may be fixed to some extent by practical or assumed conditions. The dimensions may then be tested by the above equations, that the safe working stresses may not be exceeded, the dimensions being then modified accordingly.

The steel of which both cotter and rod would ordinarily be made has range of working fiber stress as follows :

Tension, 8,000 to 12,000 (lbs. per sq. in.)
Compression, 10,000 to 16,000 (lbs. per sq. in.)
Shear, 6,000 to 10,000 (lbs. per sq. in.)

The socket, if made of cast iron, will be weak as regards tension, tendency to shear out at the end, and tendency to split. The uncertainty of cast iron to resist these is so great that the hub or socket must be very clumsy in order to have enough surplus strength. This is always a noticeable feature of the cotter type of fastening, and cannot well be avoided.

PRACTICAL MODIFICATION. The driving faces of the cotter are often made semicircular. This not only gives more shearing area at the sides of the slots, but makes the production of the slots easier in the shop. It also avoids the general objection to sharp corners—namely, a tendency to start cracks.

A practicable taper for cotters is ½ inch per foot. This will under ordinary circumstances prevent the cotter from backing out under the action of the load. When set screws against the side of the cotter, or lock nuts are used, as in Fig. 73, the taper may be greater than this, perhaps as much as 1½ inches per foot.

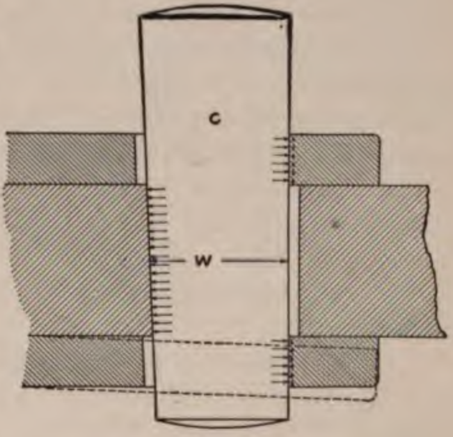


Fig. 74.

In the common use of the cotter for holding the strap at the ends of connecting rods, the strap acts like a modified form of socket. This is shown in Figs. 73 and 74. Here, in addition to holding the strap and rod together lengthwise, it may be necessary to prevent their spreading, and for this purpose an auxiliary piece G with gib ends is used. The tendency without this extra piece is shown by the dotted lines in Fig. 74.

The general mechanical fault with cottered joints is that the action of the load, especially when it constantly reverses, as in pump piston rods, always tends to work the cotter loose. Vibration also tends to produce the same effect. Once this looseness is started in the joint, the cotter loses its pure crushing and shearing action, and begins to partake of the nature of a hammer, and pounds itself and its bearing surfaces out of their true shape. Instead of a collar on the rod, we often find a taper fit of the rod in the socket; and any looseness in this case is still worse, for the rod then has end play in the socket, and by its "shucking" back and forth tends to split open the socket.

The only answer to these objections is to provide a positive locking device, and take up any looseness the instant it appears.

PROBLEMS ON KEYS, PINS, AND COTTERS.

1. Calculate the safe load in shear which can be carried on a key $\frac{1}{2}$ inch wide, $\frac{3}{8}$ inch thick, and 5 inches long. Assume $S_s = 6{,}000$.
2. Assuming the above key to be $\frac{3}{16}$ inch in hub and $\frac{3}{16}$ inch in shaft, test its proportions for crushing, at $S_c = 16{,}000$.
3. A gear 60 inches in diameter has a load of 3,000 lbs. at the pitch line. The shaft is 4 inches in diameter, in a hub, 5 inches long; and the key is a standard gib key as given in the table. Test its proportions for shearing.
4. A piston rod 2 inches in diameter carries a cotter $\frac{3}{8}$ inch thick, and has an axial load of 20,000 lbs. Calculate the average width of the cotter. $S_s = 9{,}000$.
5. Calculate fiber stress in rod in preceding problem at section through slot.
6. How far from the end of rod must the end of slot be?
7. Calculate the crushing fiber stresses on cotter, rod, and socket.
8. How far from the end of socket must the end of slot be, assuming the socket to be of steel?

BEARINGS, BRACKETS, AND STANDS.

NOTATION—The following notation is used throughout the chapters on Bearings Brackets, and Stands.

A = Area (square inches).
a = Distance between bolt centers (inches).
b = Width of bracket base (inches).
c = Distance of neutral axis from outer fiber (inches).
D = Diameter of shaft (inches).
d = Diameter of bolt body (inches).
d_1 = Diameter at root of thread (inches).
H = Horse-power.
h = Thickness of cap at center (inches).
I = Moment of inertia.
L = Length of bearing (inches).
μ = Coefficient of friction (per cent).
N = Number of revolutions per minute.
n = Number of bolts in cap.
n_1 = Number of bolts in bracket base.
P = Total pressure on bearing (lbs.).
p = Pressure per square inch of projected area (lbs).
S = Safe tensile fiber stress (lbs.).
S_s = " shearing " (lbs.).
T = Total load on bolts at top of bracket (lbs.).
t = Thickness of bracket base (inches).
x = Distance from line of action of load to any section of bracket (inches).

ANALYSIS. Machine surfaces taking weight and pressure of other parts in motion upon them are, in general, known as **bearings.** If the motion is rectilinear, the bearing is termed a **slide, guide,** or **way,** such as the cross slide of a lathe, the crosshead guide of a steam engine, or the ways of a lathe bed.

If the motion is a rotary one, like that of the spindle of a lathe, the simple word "bearing" is generally used.

In any bearing, sliding or rotary, there must be strength to carry the load, stiffness to distribute the pressure evenly over the full bearing surface, low intensity of such pressure to prevent the lubricant from being squeezed out and to minimize the wear, and sufficient radiating surface to carry away the heat generated by friction of the surfaces as fast as it is generated. Sliding bearings are of such varied nature, and exist under conditions so peculiar to each case, that a general analysis is practically impossible beyond that given in the sentence above.

Rotary bearings can be more definitely studied, as there are but two variable dimensions, diameter and length, and it is the proper relation between these two that determines a good bearing. The size of the shaft, as noted under "Shafts," is calculated by taking the bending moment at the center of the bearing, combining it with the twisting moment, and solving for the diameter consistent with the assumed fiber stress. But this size must then be tried for deflection due to the bending load, in order that the requirement for stiffness may be fulfilled. When this is accomplished, the friction at the bearing surface may still generate so much heat that the exposed surface of the bearing will not radiate it as fast as generated, in which case the bearing gets hotter and hotter, until it finally burns out the lubricant and melts the lining of the bearing, and ruin results.

The heat condition is usually the critical one, as it is very easy to make a short bearing which is strong enough and amply stiff for the load it carries, but which nevertheless is a failure as a bearing, because it has so small a radiating surface that it cannot run cool.

The side load which causes the friction and the consequent development of heat, is due to the pull of the belt in the case of pulleys, the load on the teeth of gears, the pull on cranks and levers, the weight of parts, etc. If we could exert pure torsion on shafts without any side pressure, and counteract all the weight that comes on the shaft, we should not have any trouble with the development of heat in bearings; in fact, there would theoretically be no need of bearings, as the shafts would naturally spin about their axes, and would not need support.

It can be shown, theoretically, that the radiating surface of a bearing increases relatively to the heat generated by a given side load, *only when the length of the bearing is increased.* In other words, increasing the diameter and not the length, theoretically increases the heat generated per unit of time just as much as it increases the radiating surface; hence nothing is gained, and heat accumulates in the bearing as before. This important fact is verified by the design of high-speed bearings, which, it is always noted, are very long in proportion to their diameter, thus giving relatively high radiating power.

Bearings must be rigidly fastened to the body of the machine in some way, and the immediate support is termed a **bracket, frame,** or **housing.** "Bracket" is a very general term, and applies to the supports of other machine parts besides "bearings." It is especially applicable to the more familiar types of bearing supports, and is here introduced to make the analysis complete.

The bracket must be strong enough as a beam to take the side load, the bending moment being figured at such points as are necessary to determine its outline. It may be of solid, box, or ribbed form, the latter being the most economical of material, and usually permitting the simplest pattern. The fastening of the bracket to the main body of the machine must be broad to give stability; the bolts act partly in shear to keep the bracket from sliding along its base, and partly in tension to resist its tendency to rotate about some one of its edges, due to the side pull of the belt, gear tooth, or lever load, as the case may be. The weight of the bracket itself and of the parts it sustains through the bearing, has likewise to be considered; and this acts, in conjunction with the working load on the bearing, to modify the direction and magnitude of the resultant load on the bracket and its fastening.

Stands are forms of brackets, and are [illegible] analysis. The distinction is by no means [illegible] we usually think more readily of a stand as having an upright or inverted position with reference to the ground. The ordinary "hanger" is a good example of an inverted stand; and the regular "floor stand," found on jack shafts in some power houses, is an example of the general class.

THEORY. As the method of calculation of the diameter of the shaft, as well as its deflection, has been considered under "Shafts," we may assume that the theoretical study of bearings starts on a given basis of shaft diameter D. The main problem then being one of heat control, let us first calculate the amount of heat developed in a bearing by a given side load. The force of friction acts at the circumference of the shaft, and is equal to the coefficient of friction times the normal force; or, for a given side load P, Fig. 75, the force of friction would be μP. The peripheral speed of the shaft for N revolutions per minute is $\frac{\pi DN}{12}$ feet per minute. As work is "force times distance," the work wasted in friction is then $\frac{\mu P \pi DN}{12}$ foot-pounds per minute. One horse-power being equal to 33,000 foot-pounds per minute, we have the equation,

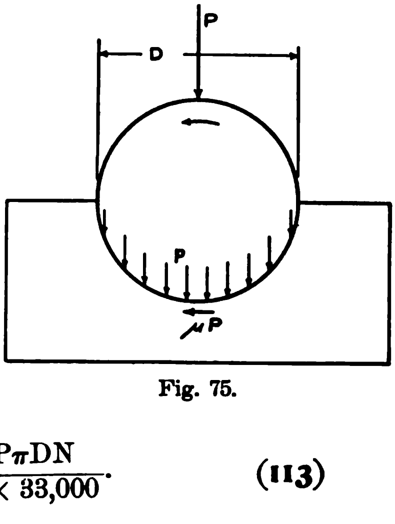


Fig. 75.

$$H = \frac{\mu P \pi DN}{12 \times 33{,}000}. \qquad (113)$$

The value of μ for ordinary, well-lubricated bearings, may run as low as 5 per cent; but as the lubrication is often impaired, it quite commonly rises to 10 or 12 per cent. A value of 8 per cent is a fair average. This amount of horse-power is dissipated through the bearing in the form of heat. If we could exactly determine the ability that each particle of the metal around the shaft had to transmit the heat, or to pass it along to the outside of the casting, and if we could then determine the ability of the articles of air surrounding the casting to receive and carry away this heat, we could calculate just such proportions of the bearing and its casing as would never choke or retard this free transfer of heat away from the running surface.

Such refined theory is not practical, owing to the complicated shapes and conditions surrounding the bearing. The best that we can do is to say that for the usual proportions of bearings the side load may exist up to a certain intensity of "pressure per square inch of projected area" of bearing, or, in form of an equation,

$$P = pLD. \qquad (114)$$

The constant p is of a variable nature, depending on lubrication, speed, air contact, and other special conditions. For ordinary bearings having continuous pressure in one direction, and only fair lubrication, 400 to 500 is an average value. When the pressure changes direction at every half-revolution, the lubricant has a better chance to work fully over the bearing surface, and a higher value is permissible, say, 500 to 800. In locations where mere oscillation takes place, not continuous rotation, and reversal of pressure occurs, as on the cross-head pin of a steam engine, p may run as high as 900 to 1,200. On the crank pins of locomotives, which have the reversal of pressure, and the benefit of high velocity through the air to facilitate cooling, the pressures may run equally high. On the eccentric crank pins of punching and shearing machines, where the pressure acts only for a brief instant and at intervals, the pressure ranges still higher without any dangerous heating action.

When a bearing, for practical reasons, is provided with a cap held in place by bolts or studs, the *theory* of the cap and bolts is of little importance, unless the load comes directly against the cap and bolts. Except in the latter case, the proportions of the cap and the size of the bolts are dependent upon general appearance and utility, it being manifestly desirable to provide a substantial [illegible] even though some excess of strength is thereby introduced. For the worst case of loading, however, which is when the

ed upon by the direct load, such as P in Fig. 76, we have

of a centrally loaded beam supported at the bolts.

that the beam is partially fixed at the ends by the

nut; also that the load P, instead of being concentrated at the center, is to some extent distributed. It is hardly fair to assume the external moment equal to $\frac{Pa}{8}$ or $\frac{Pa}{4}$, the one being too small, perhaps, and the other too large. It will be reasonable to take the external moment at $\frac{Pa}{6}$, in which case, equating the external moment to the internal moment of resistance,

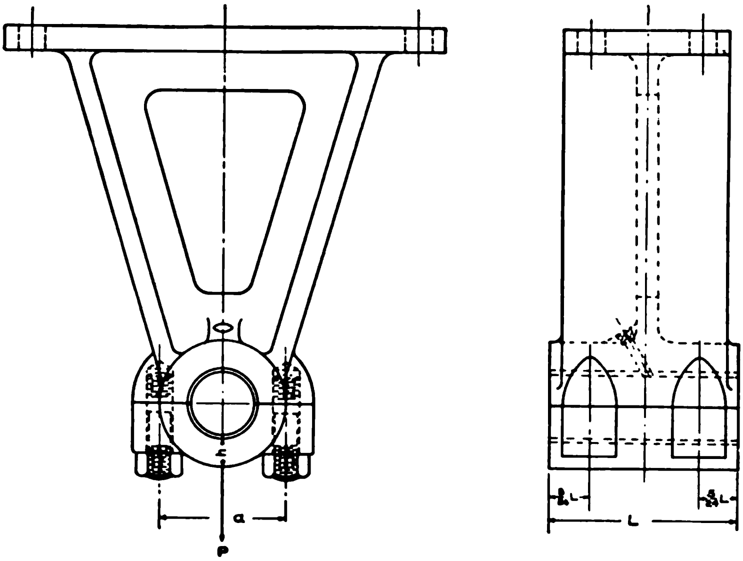


Fig. 76.

$$\frac{Pa}{6}=\frac{SI}{c}=\frac{SLh^2}{6}, \qquad (115)$$

from which, the length of bearing being known, we may calculate the thickness h.

One bolt on each side is sufficient for bearings not more than 6 inches long, but for longer bearings we usually find two bolts on a side. The theoretical location for two bolts on a side, in order that the bearing may be equally strong at the bolts and at the center of the length, may be shown by the principles of mechanics to be $\frac{5}{24}$ L from each end, as indicated in Fig. 76.

The bolts are evidently in direct tension, and if equally loaded would each take their fractional share of the whole load P. This is difficult to guarantee, and it is safer to consider that $\frac{2}{3}$ P may be taken by the bolts on one side. On this basis, for total number of bolts n, equating the external force to the internal resistance of the bolts, we have :

$$\frac{2}{3} P = \frac{S \pi d_1^2}{4} \times \frac{n}{2}, \tag{116}$$

from which the proper commercial diameter may be readily found.

The bracket may have the shape shown in Fig. 77. The portion at B is under direct shearing stress; and if A be the area at this point, and S_s the safe shearing stress, then, equating the external force to the internal shearing resistance,

$$P = AS_s. \tag{117}$$

The same shear comes on all parts of the bracket to the left of the load, but there is an excess of shearing strength at these points.

At the point of fastening, the bolts are in shear, due to the same load, for which the equation is

$$P = \frac{\pi d^2}{4} n_1 S_s. \tag{118}$$

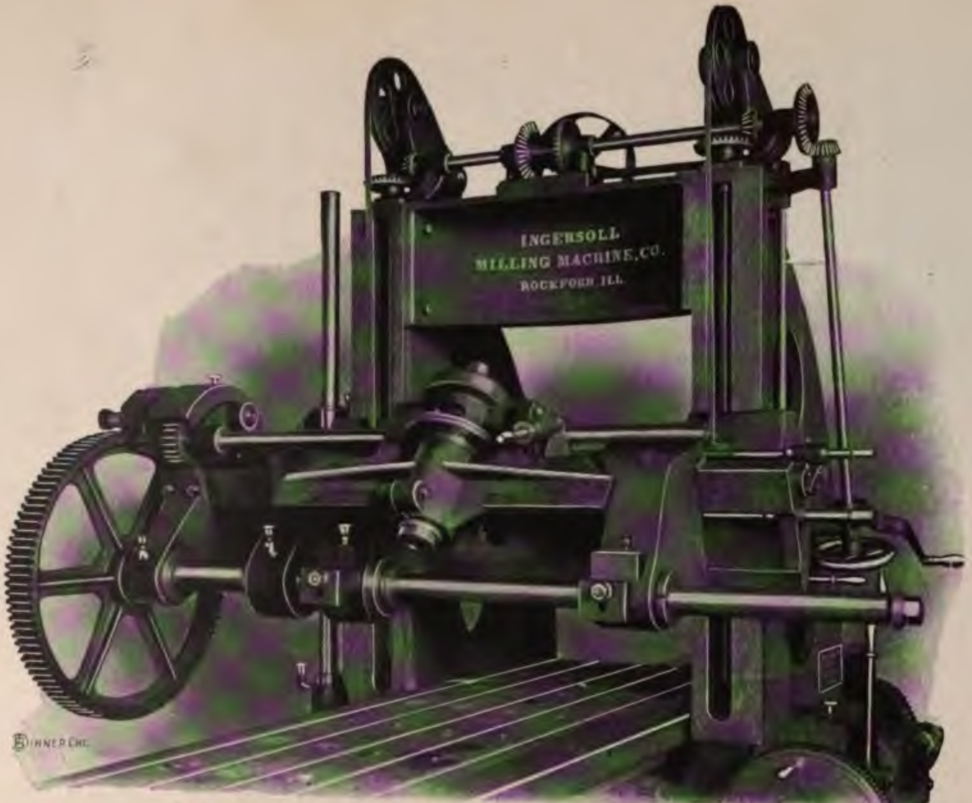
For the upper bolts, the case is that of direct tension, assuming that the whole bracket tends to rotate about the lower edge E. To find the load T on these bolts, we should take moments about the point E, as follows:

$$PL_1 = Tl; \text{ or } T = \frac{PL_1}{l}. \tag{119}$$

Then, equating the external force to the internal resistance,

$$T = \frac{PL_1}{l} = \frac{\pi d_1^2}{4} \times \frac{n_1}{2} S. \tag{120}$$

The upper flange is loaded with the bolt load T, and tends to break off at the point of connection to the main body of the bracket, the external moment, therefore, being Tr. The section of the flange is rectangular; hence the equation of external and internal moments is:



SWINGING VERTICAL ATTACHMENT FOR MILLING MACHINE.

$$Tr = \frac{PL_1}{l}r = \frac{Sbt^2}{6}. \qquad (121)$$

It may be noted that the lower bolts act on such a small leverage about E, that they would stretch and thus permit all the load to be thrown on the upper bolts; this is the reason why they are not subject to calculation for tension.

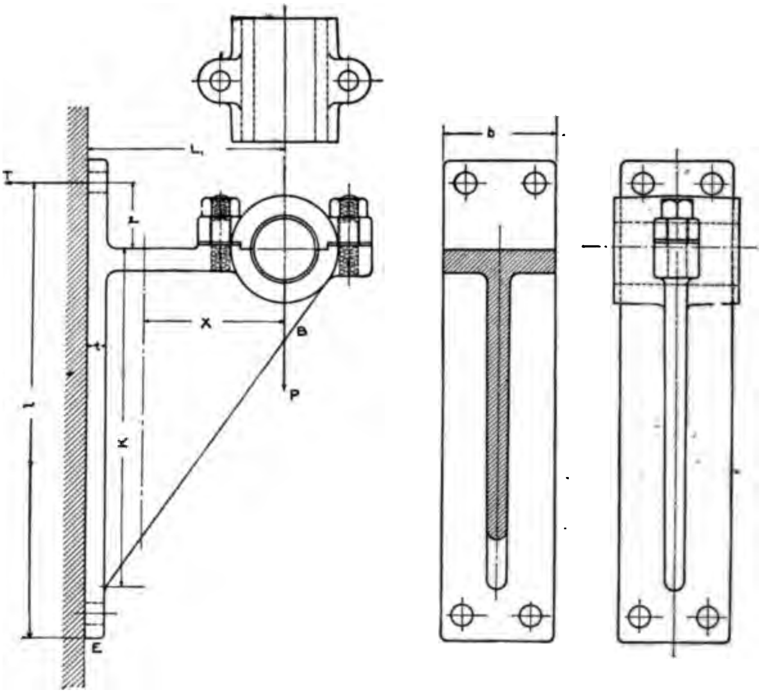


Fig. 77.

The section of the bracket to the left of the load P is dependent upon the bending moment, for, if this section is large enough to take the bending moment properly, the shear may be disregarded. It should be calculated at several points, to make sure that the fiber stress is within allowable limits. The general expression for the equation of moments is, for any section at leverage x,

$$Px = \frac{SI}{c}, \qquad (122)$$

from which, by the proper substitution of the moment of inertia of the section, the fiber stress can be calculated. The moment of inertia for simple ribbed sections can be found in most handbooks. The process of solution of the above equation, though simple, is apt to be tedious, and is not considered necessary to illustrate here.

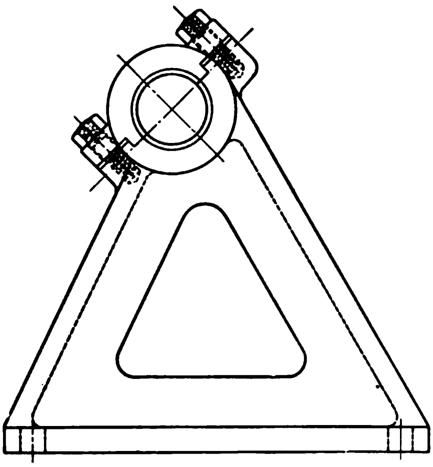


Fig. 78.

PRACTICAL MODIFICATION. Adjustment is an important practical feature of bearings. Unless the proportions are so ample that wear is inappreciable, simple and ready adjustment must be provided. The taper bushing, Fig. 79, is neat and satisfactory for machinery in which expense and refinement are permissible. This is true of some machine tools, but is not true of the general "run" of bearings. The most common form of adjustment is secured by the plain cap (which may or may not be tongued into the bracket), with liners placed in the joint when new, which may subsequently be removed or reduced so as to allow the cap to close down upon the shaft. Several forms of cap bearings are illustrated in Figs. 80, 81, and 82.

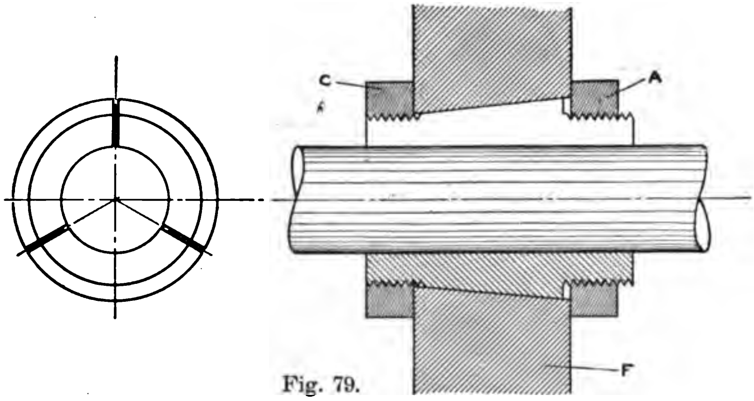


Fig. 79.

Large engine shaft bearings have special forms of adjustment by means of wedges and screws, which take up the wear in all directions, at the same time accurately preserving the alignment of the shafts; but this refinement is seldom required for shafts of ordinary machinery.

In cases where the cap bearing is not applicable, a simple bushing may be used. This may be removed when worn, and a new one inserted, the exact alignment being maintained, as the outside will be concentric with the original axis of shaft, regardless of the wear which has taken place in the bore.

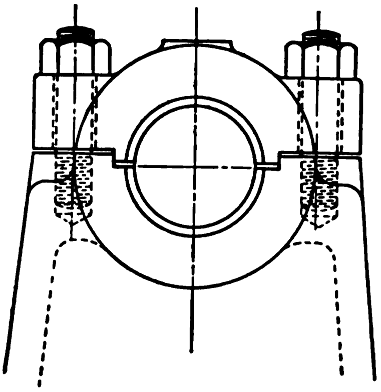


Fig. 80.

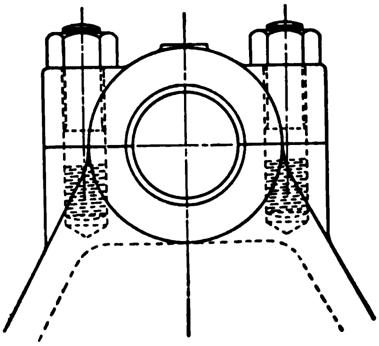


Fig. 81.

The lubrication of bearings is a part of the design, in that the lubricant should be introduced at the proper point, and pains taken to guarantee its distribution to all points of the running surface. The method of lubrication should be so certain that no excuse for its failure would be possible. Grease is a successful lubricator for heavy loads and slow speeds, oil for light loads and high speeds.

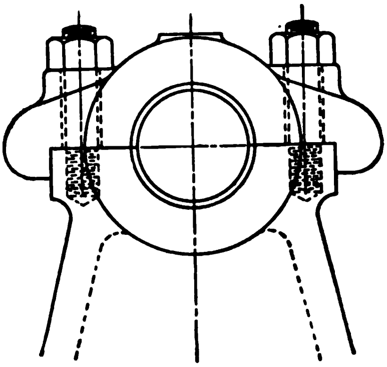


Fig. 82.

In order to insure the lubricant reaching the sliding surfaces and entering between them, it must be introduced at a point where the pressure is moderate, and where the motion of the parts will naturally lead it to all points of the bearing. Grooves and channels of ample size assist in this regard. A special form of bearing uses a ring riding on the shaft to carry the oil constantly from a small reservoir beneath the shaft up to the top, where it is distributed along the bearing and finally flows back to the reservoir and is used again.

The materials of which bearings are made vary with the service required and with the refinement of the bearing. Cast iron makes an excellent bearing for light loads and slow speeds, but it is very apt to "seize" the shaft in case the lubrication is in the least degree impaired. Bronze, in its many forms of density and hardness, is extensively used for high-grade bearings, but it also has little natural lubricating power, and requires careful attention to keep it in good condition.

Babbitt, a composition metal, of varying degrees of hardness, is the most universal and satisfactory material for ordinary bearings. It affords a cheap method of production, being poured in molten form around a mandrel, and firmly retained in its casing or shell through dovetailed pockets into which the metal flows and hardens. It requires no boring or extensive fitting. Some scraping to uniform bearing is necessary in most cases, but this is easily and cheaply done. Babbitt is a durable material, and has some natural lubricating power, so that it has less tendency to heat with scanty lubrication than any of the materials previously mentioned. Almost any grade of bearing may be produced with babbitt. In its finest form the babbitt is hammered, or pened, into the shell of the bearing, and then bored out nearly to size, a slightly tapered mandrel being subsequently drawn through, compressing the babbitt and giving a polished surface.

A combination bearing of babbitt and bronze is sometimes used. In this the bronze lies in strips from end to end of the bearing, and the babbitt fills in between the strips. The shell, being of bronze, gives the required stiffness, and the babbitt the favorable running quality.

PROBLEMS ON BEARINGS, BRACKETS, AND STANDS.

1. The allowable pressure on a bearing is 300 pounds per

square inch of projected area. What is the required length of the bearing if the total load is 4,500 pounds and the diameter is 3 inches?

2. The cross-head pin of a steam engine must be 2.5 inches in diameter to withstand the shearing strain. If the maximum pressure is 10,000 pounds, what length should be given to the pin?

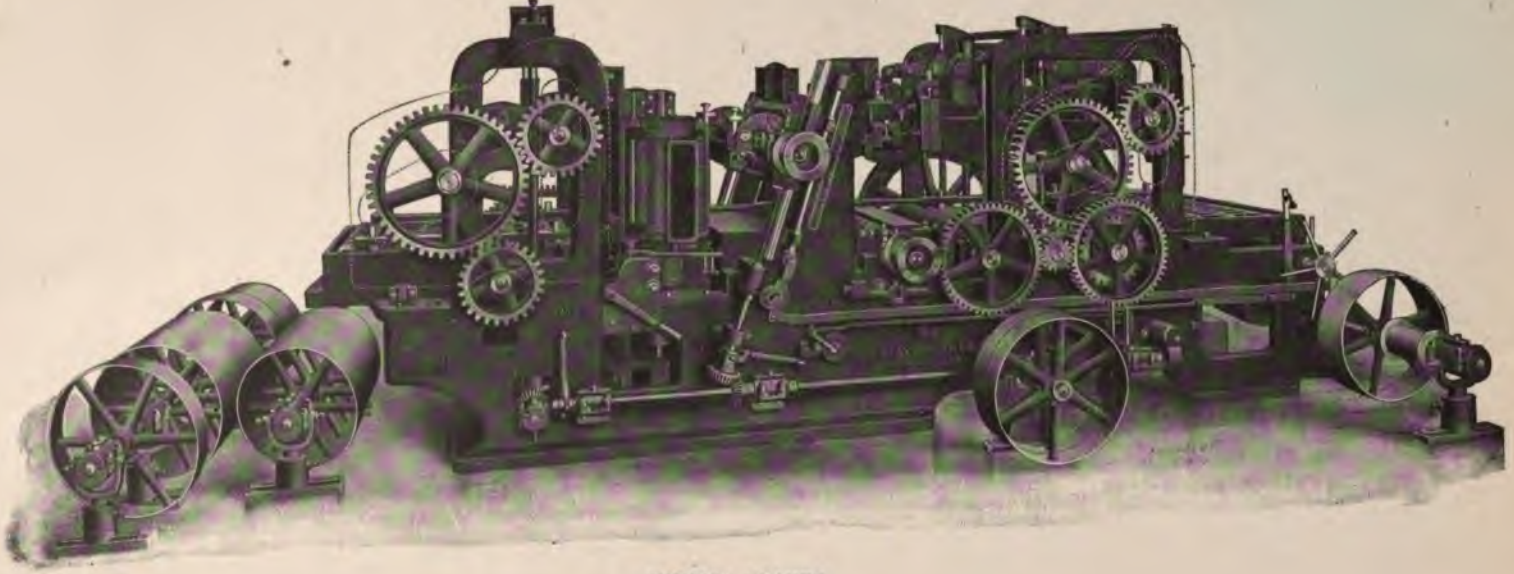
3. The journals on the tender of a locomotive are $3\frac{1}{2} \times 7$ inches. The total weight of the tender and load is 60,000 pounds. If there are 8 journals, what is the pressure per square inch of projected area?

4. What horse-power is lost in friction at the circumference of a 3-inch bearing carrying a load of 6,000 pounds, if the number of revolutions per minute is 150 and the coefficient of friction is assumed to be 5 per cent?

5. The cast-iron bracket in Fig. 77 has a load P of 1,000 pounds. Determine the fiber stress in the web section at the base of the bracket if the thickness is taken at $\frac{1}{2}$ inch, and $L_1 = 12$ inches; $l = 20$ inches; $k = 11$ inches; $t = 1$ inch.

6. Calculate the diameter of the bolts at the top of the bracket.

7. Assuming r equal to 6 inches, what is the fiber stress at the root of flange?



TIMBER PLANER.
J. A. Fay and Egan Co.

PATTERN MAKING.

PART I.

Pattern Making dates back to the time when the first article was made from molten metal for the use of man. The pattern must precede the making of its metal counterpart, and is therefore the first subject to be treated in the working of metal.

Qualifications of the Pattern Maker. The pattern maker is essentially a worker in wood, though, where many castings are to be made from the same pattern, the final or working pattern is made of metal. These metal patterns are very serviceable, and leave the sand more easily and cleanly than those made of wood. Metal patterns are always necessary when the work is of a delicate or very light character. In all such cases, however, the first pattern —from which the metal pattern is to be moulded—is made of wood, allowance being made for double shrinkage, and, when necessary, for double finish. The necessity for this will be clearly explained farther on.

The pattern maker should possess a practical knowledge of the properties of metals. First of all, he must understand the **shrinkage** of metals, that is to say, how much smaller the cold casting will be than the molten mass as it flows into the mould; he should know what the **strength** of the metal is; he should be familiar with the relative **rapidity of cooling,** so that internal stresses in the body of the completed casting may be avoided as much as possible; he also should know enough about the practical work of the moulder to decide upon the peculiarities of construction of the pattern for any given piece; and he must be sufficiently skilled as a draftsman to lay out, without the assistance of the designer, the drawings of the piece to be made. It is very true, however, that there are many good pattern makers who do not possess all of these qualifications.

The last-mentioned qualification is one of the most important. The drawings furnished the pattern maker are usually on a small scale.

In order to work to the best advantage, he must reproduce a part or all of them at full size, as working drawings. To do this in such a way that the lines and curves of the finished pattern shall be graceful and artistic in appearance, will require the same nicety and precision of workmanship that are demanded in the drafting room, and it is essential that the pattern maker have the same complete knowledge of the principles involved. To the extent, then, of being able, when necessary, to make a full-sized drawing of the article to be made, the pattern maker must be a draftsman.

In large establishments, where all the work comes to the pattern shop in the form of carefully executed drawings, the pattern maker is the means of putting the ideas of others into tangible shape. In smaller places, where no draftsman is employed, the pattern maker will be called upon to work out the designs for which he is to make his patterns, and he thus becomes the real designer.

Finally, the pattern maker is seldom required to make two patterns that are identically the same. His work, therefore, is varied, and he must be prepared to apply to the solution of new problems that arise such principles as he may already have learned.

Materials for Patterns. As patterns are subjected to more or less rough usage, and are alternately wet and dry, it follows that the ideal material is one whose hardness is such that it will withstand the wear and tear of handling and at the same time be impervious to the effects of moisture. Such material is to be found in the metals, but, as the cost of working these into the proper shape is considerable, some kind of **wood** is usually substituted.

Kind of Wood Used. If, then, wood is to be used, another qualification is to be added—namely, it should be easily worked. The best wood for the purpose is undoubtedly **white pine.** Care should be exercised in the inspection of the wood, to see that it is **clear, straight-grained,** and **free from knots.**

The straightness of the grain can be determined by the appearance of the sawn face. This should present an even roughness over the whole surface. The wood should be *seasoned* in the open air, but preferably sheltered by a roof, and should be piled so that the air will have free access to all parts of the plank. In the natural process of air drying, the moisture slowly works out to the surface and evaporates until the wood is dry or "seasoned." Such stock is firmer, stronger, more elastic, and less affected by heat and cold and by moisture and dryness, than kiln-dried lumber. In kiln drying, the outside surfaces and ends of the boards are dried more rapidly than the inside, producing strains that cause the wood to bend and warp while the pattern is in the process of construction. For this reason it is better to "build up" the larger pieces of a pattern by gluing together three or more (*never two*) pieces of thinner stock. When the patterns are of moderate size the stock to be glued may vary from ⅜ inch to 1 inch or even 1¼ inches in thickness, in proportion to the size required. Stock of 2 inches thickness or over can seldom be found sufficiently seasoned; and, if forced by kiln-drying, it will be checked and strained to an extent that will render it useless for pattern work.

While pine is in general the ideal wood for pattern work, it is soft and weak, so that, if small and strong patterns are desired, a harder wood is usually employed. **Mahogany** is much used for this purpose. Like pine, it is not liable to warp, and, when straight-grained, it is worked with comparative ease. There are many varieties of this beautiful wood, varying greatly in firmness of texture. The soft bay wood, often sold as genuine mahogany, should be avoided for patterns, being but little harder than pine. **Cherry** is also extensively used, but is not so easily worked to a smooth surface as mahogany, and is more liable than the latter to warp and to be affected by moisture. **Black walnut, beech,** and **maple** are used to some extent. Black walnut is stronger than cherry, but, like beech and maple, is likely to warp.

It may be stated then, that, in the United States, white pine is the material commonly employed for pattern making. Lumber 1 inch, 1¼ inches, and 1½ inches thick will be found convenient in the construction of such patterns as are most commonly called for. It will be a great saving of time and labor, after the lumber has been carefully selected, to have it taken to the planing mill and dressed on two sides to the following thicknesses:

One-inch, dressed on two sides to	⅞ inch;
One and one-quarter-inch, dressed on two sides to	1⅛ inch;
One and one-half-inch, dressed on two sides to	1⅜ inch;

and, if such can be found well seasoned, a small quantity of two-inch, dressed to 1¾ inches.

In addition to these sizes there should be a moderate amount of 1-inch resawed and dressed to $\frac{3}{8}$ inch or to $\frac{5}{16}$ inch; and the same amount of $1\frac{1}{4}$-inch resawed and dressed to $\frac{1}{2}$ inch. The two last thicknesses are used for gluing and building up the rims of pulleys, gear wheels, and other light work where strength and durability are required.

Warping and Twisting of Wood. Observation shows that if one side of a board is kept damp and the other dried, the former will expand so that the plank, although originally straight, becomes curved as in Fig. 1. Or if one side of a board is exposed to the air, while the other is more or less protected, as in the stack of boards shown in Fig. 2, the exposed side of the upper board will give off its moisture more rapidly than the other side, and the board will warp or bend in the direction shown by the dotted lines. The second board will also "draw" and to some extent follow the first, being in turn followed by the third, and so on until the entire stack is warped and bent.

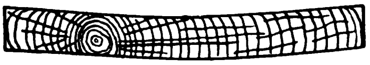


Fig. 1.

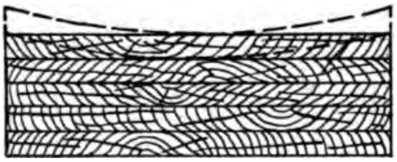


Fig. 2.

The same will be found true of a well-seasoned board if after being planed it is allowed to lie on its side on the work-bench. The upper side will give off its moisture more freely than is possible for the under side; the latter being protected and having its moisture retained by the bench. The lower side of the board is thus caused to expand, and the upper to contract, with the result that the board, although originally planed straight, becomes curved. For this reason all lumber, even if well-seasoned, should be so placed in racks, or on end, that the air may have free access to both sides of the planks; and newly planed boards, however dry and well seasoned, should never be stacked together, but so placed that both sides will be exposed alike.

This tendency to warp is explained to some extent by the porous nature of all woods, and their inclination to give off or to absorb moisture according to the condition of the surrounding atmosphere. As there is always more or less moisture in the air, and lumber of all kinds contains an amount of moisture which is ever changing according to the conditions of the surrounding atmosphere; this causes corresponding expansion or contraction of the wood.

Even under cover and in a dry place, wood has a tendency to warp on account of the greater shrinkage of the newer as compared with the older cells of the wood tissue or fiber in the side of the board nearest to the outside or sap wood of the tree. The inner side A of the board (Fig. 3) being closer to the heart wood, is older than the side B; its cells are firmer and more compact than those of B. As the board seasons, the newer and more open cells of the side B will shrink faster and to a greater extent than those of A, thus causing the board to draw or warp in the direction indicated by the dotted lines.

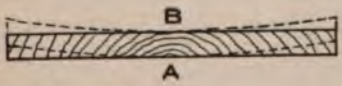


Fig. 3.

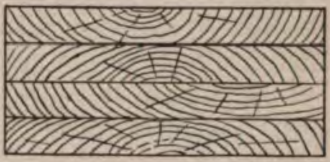


Fig. 4.

In gluing or building up stock for a pattern, this tendency may be corrected to some extent, by reversing the grain of the pieces that are to be glued, and placing two outsides (as B, Fig. 3) or two insides (as A, Fig. 3) together. This is fully illustrated in Fig. 4.

In gluing very thin pieces together for the webs or centers of pulleys and for other purposes, it is often necessary to reverse the grain of the pieces, or to place the grain of *one piece at right angles to that of the other*, for the purpose of gaining greater strength and stiffness. In such cases, if only two thin pieces are used, the result, after they have been glued and dried, will be to some extent as shown in Fig. 5, the shrinkage and strain of the end grain crosswise of the board at *a*, being sufficient to bend the opposing thin board lengthwise of the grain at *b*, while on the side *cd*, the curve will be reversed for the same reason. *Whenever it is necessary to cross the grain of thin pieces for a pattern, three or more pieces should be used*, which will give satisfactory results if placed together as shown in Fig. 6.

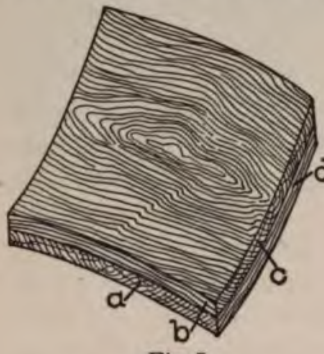


Fig. 5.

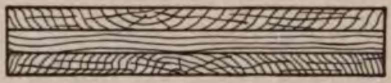


Fig. 6.

When thin circular disks of large size are to be glued up for patterns of any kind, the strongest, stiffest, and most satisfactory results will be obtained if the pieces are fitted and glued tangentially to the hub or other center or opening in the disk, as shown in Fig. 7. The grain of the wood must run lengthwise, and parallel to the longest side of each sector; and, after the pieces have been fitted together, a thin groove is cut in the edge of each, in which thin tongues of wood are inserted and glued, as illustrated in Fig. 8. Two disks are glued up, and one is turned over so as to reverse the grain of the sectors of one disk on that of the other, as shown by the dotted lines. The disks are then glued together, making a very rigid construction, and one which, owing to the continual change in the direction of the grain, will not warp.

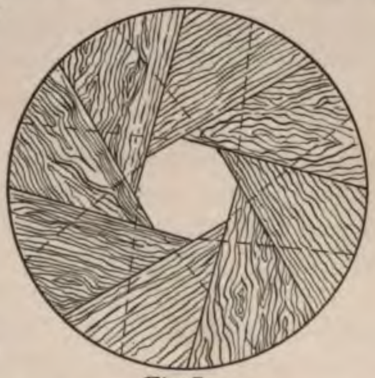


Fig. 7.

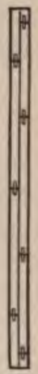


Fig. 8.

Should a wide and thin piece of a single thickness be required for a pattern, the board from which it is to be made should be ripped into strips of two, three, or four inches in width (according to the width of the required board), and the strips glued together again with each alternate strip reversed, as shown in Fig. 9. In this way the tendency to warp is to a great extent corrected, each narrow strip being inclined to warp in an opposite direction to that of its neighbor.

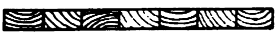


Fig. 9.

TOOLS.

While many of the tools used by the pattern maker are identical with those used by the carpenter and cabinet maker, yet the conditions that govern the construction of patterns for the molding of metals, together with the required accuracy in dimensions and the methods of construction used to guard against warping, distortion, and breaking, have very little in common with the workmanship and methods of the carpenter, the wood turner or the cabinet maker.

Following is a descriptive list of the more essential tools used in pattern making, accompanied with instructions in their use.

HAND SAWS.

Rip Saw and Crosscut Saw. Hand saws are of two kinds—**rip** and **crosscut.** The former, as the name indicates, is for cutting *with* the grain, or lengthwise of the board to be sawed. In Fig. 10 is illustrated a rip saw having 5½ points to the inch, which will work rapidly and with ease in pine and other soft woods. If mahogany, cherry, or other hard wood is to be ripped, a six-point saw should be used. Rip saws should be filed with all the bevel on the back of the tooth, as shown at *b* in Fig. 10, the front or "throat" of the tooth being at right angles to, or "square" with, the tooth edge of the blade, as at *a* in the same figure. The position of the line *cd*, whether perpendicular or slanting, is called the "hook" or "pitch" of the tooth.

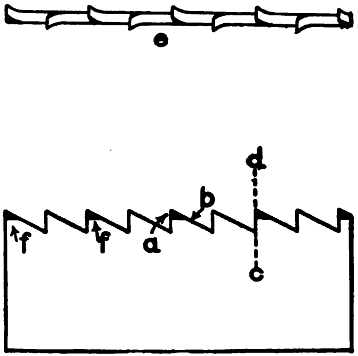


Fig. 10.

Rip saws should be filed square across; that is, the file should be held horizontal and at right angles to the side of the blade, always filing each alternate tooth from the opposite side of the saw; this, if done by beginning at the heel and working the file toward the point of the blade, will give a very slight bevel to the back edge of the tooth, causing it to cut cleaner and with less set than if filed otherwise.

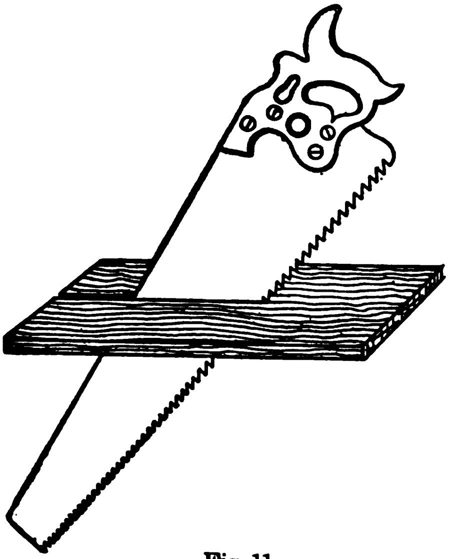


Fig. 11.

Rip saws require very little set for use in dry, well-seasoned lumber, such as is always used in pattern making. The teeth should be "set," or bent, only at the points, as shown at *e* and *f* in Fig. 10; and in no case should the set exceed more than half the depth of the tooth.

When the points only are set, the saw will work more freely, and the blade of the saw will not be "sprung," or bent, in setting In using a rip saw, the front or cutting edge of the saw blade should be held at an angle of about 45° to the board, as shown in Fig. 11. This brings the back of the tooth nearly at right angles to the fibres of the wood, and insures a shearing cut. For fine work and well-seasoned material, hand saws may be bought ground so thin on the back as to require no set. Such tools work very smoothly and easily, cutting away less wood and doing better work than saws that have been set.

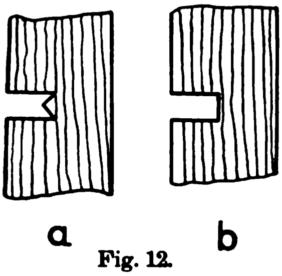


Fig. 12.

The crosscut saw really severs or cuts the fibres of the wood twice, as shown at *a* in Fig. 12, the intervening projections being loosened dust by the thrust of the saw, kerf, as shown at *b* (Fig. 12).

A crosscut saw for ordinary work should have five or six points to the inch; but for fine work ten or twelve points would be better, especially for dry woods, either soft or hard.

A section of a 6-point crosscut saw is shown in Fig. 13, and one of an 13½-point in Fig. 14.

In considering rip saws we find that the rake or bevel is all on the back of the tooth. In crosscut saws the rake is on the side of the tooth, as shown at *a* (Fig. 13.) In ripping, the point of the tooth acts as a chisel, cutting off the fibers of the wood, each tooth chiseling off a shaving as it passes through the board; but in crosscutting, the side of the tooth does the cutting, and therefore must have its bevel on the side.

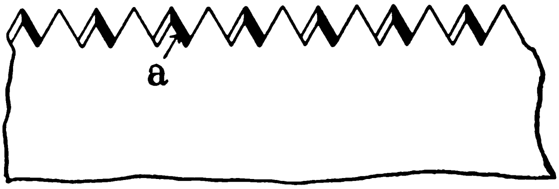


Fig. 13.

In Fig. 13 the bevel or **fleam** of the tooth is about 45°, and, as shown, there is no hook or pitch, the angle being the same on both the front and back of the tooth. This form of tooth works well in wet or in very soft wood; but for wood that is well seasoned, and for all the harder and firmer woods, the pitch of the front of the tooth should be at an angle of about 60° to the tooth edge of the blade, as shown in Fig. 15, and at *b* in Fig. 16. The amount of pitch in the teeth of a saw may be varied as demanded for different purposes or for different woods, but in all cases should be such as

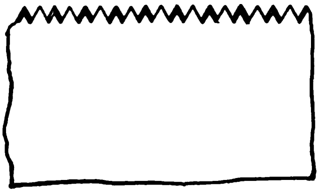


Fig. 14.

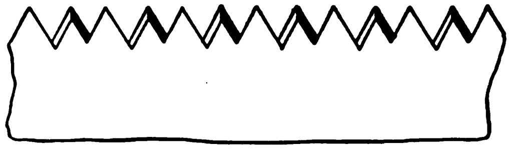


Fig. 15.

to loosen and carry out the intervening wood. Otherwise this would have to be rasped or filed out by the continued action of the saw.

The fleam of the side of the crosscut saw tooth is very important. When filing, the file should be held horizontally and at an angle of about 45° to the side of the saw, lengthwise of the blade, as illustrated in Fig. 16; and each alternate tooth must be filed from the opposite side of the blade, beginning at the heel and filing toward the point of the saw.

The objection is often raised by saw filers, that in filing from the handle end of the saw toward the point, a feather edge is made by the file and turned backward on the point of the tooth. The first thrust of the saw through the board, however, will remove this feather edge entirely; whereas, if the filing be done from the point of the saw toward the handle, it is necessary to file the teeth bent toward the operator, which causes the saw to vibrate, or "chatter;" and this not only renders good, even filing impossible, but breaks the teeth of the file.

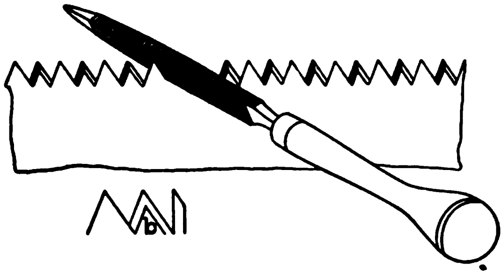
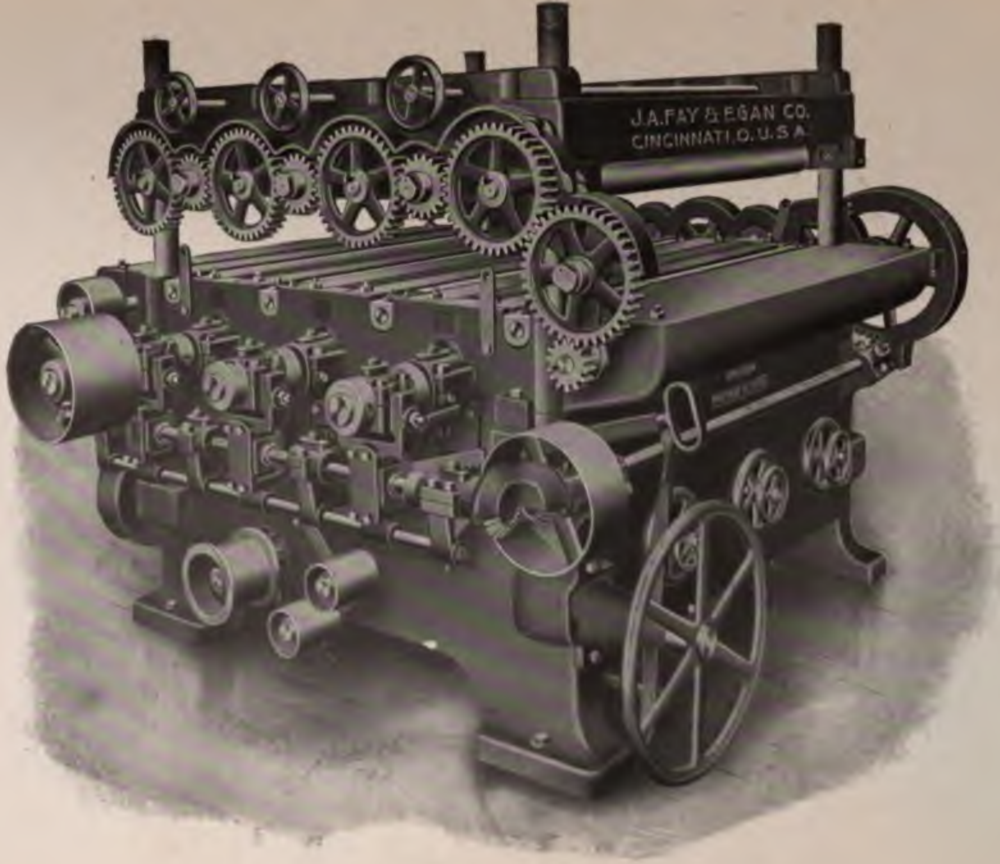


Fig. 16.

For hand and back saws, a saw-set that acts on the principle of the hammer and anvil, such as the one illustrated in Fig. 17, is best. The spring sets, so much in use, will not give so regular and even a set to the teeth as will one or more light blows with the hammer on the beveled face of the anvil. By this method the tooth is not bent or sprung beyond the position in which it is intended to remain, and the blade of the saw is not bent or affected by the stroke of the hammer on the point of the tooth. A saw-set of the kind illustrated in Fig. 17 can be adjusted to set the points of the teeth to any depth desired; and, even if repeated light blows are given, the tooth cannot be bent beyond the required distance. The blow may be struck on *a* with a light mallet; or it may be struck from below with the operator's foot on a treadle connected with *e*, leaving both hands free to hold and to guide the saw.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In setting a saw, it is always better to use two or three light blows on a tooth than to try to do the work with one heavy blow; and this is especially the case if the saw is hard, as all good and well-tempered saws should be.

The **back saw** illustrated in Fig. 18 is used as a bench saw for light or fine work, and for fitting and dovetailing. Saws of this type are made from 8 to 14 inches in length, the 10- and 12-inch being convenient sizes for general work. As the metal back holds and stiffens the saw, a thin blade should always be selected; and the methods of filing, jointing and setting are the same as already described for hand saws. At least two back saws will be found necessary, one filed for crosscutting, and the other filed as a rip saw for cutting *with* the grain of the wood, as in the cutting of tenons and dovetails.

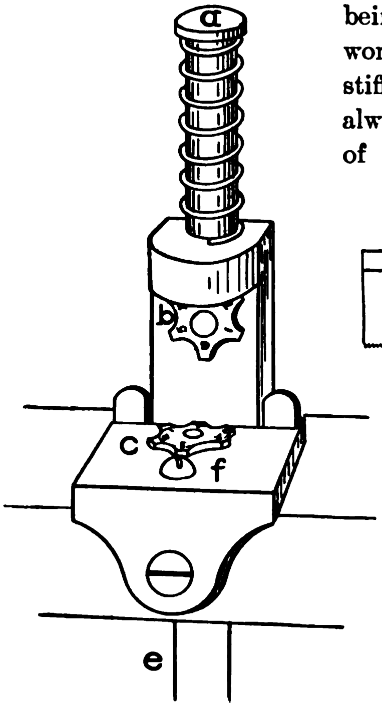


Fig. 17.

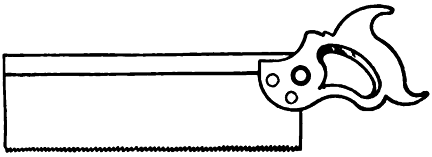


Fig. 18.

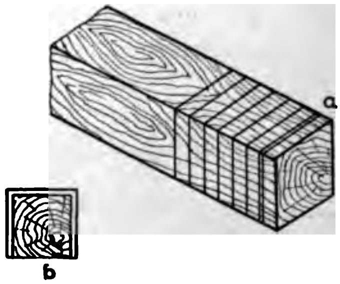


Fig. 19.

EXERCISE.

While for those who have had experience in carpentry the following exercise in the use of the back saw may not be necessary, it is recommended to all beginners who wish to acquire skill in the use of this important tool.

Take any block of wood from 12 inches to 16 inches long, about 2 inches wide, and about 1¾ inches in thickness. With try-square and a sharp-pointed pocketknife, lay it out as illustrated in Fig. 19, on the upper, front, and back sides of the block. The knife-cuts must be at least 1/32 inch deep, and about ¼ inch distant from each other. Next proceed to saw up the block into thin sections, sawing each time so that the saw kerf will be just outside of, but close to the knife line, as indicated at *a*.

The saw-cut through the block should be true to each of the three lines; and while the saw passes along one side of the line, its teeth should not scratch the opposite side of the knife-cut, but should leave a smooth, clean angle of the knife-cut on the block, as shown at *b* in Fig. 19, while at the same time it should be so close to the line as to leave no wood to be smoothed off with plane or chisel.

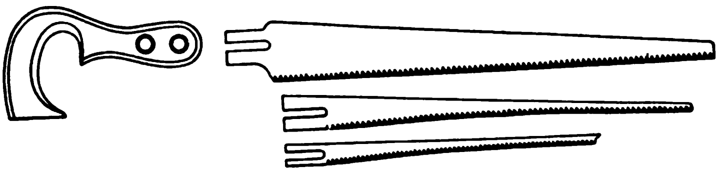


Fig. 20.

A few hours' thorough and careful practice of this exercise will enable any one to use the saw successfully.

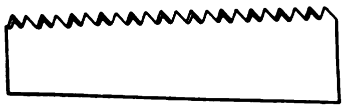


Fig. 21.

Compass Saw. As the work of the compass saw, illustrated in Fig. 20, will be both *with* and *across* the grain of the wood, the best form of tooth will be that shown in Fig. 21, having more pitch, and slightly less bevel, than the crosscut saw. A crosscut saw will rip better than a rip saw will crosscut; hence the shape of tooth should be between the two. Compass saws are ground very thin on the back of the blade, but in order to turn easily they should be set the same as hand saws. And here we wish to impress on the beginner the necessity of keeping his saw—and indeed all other cutting tools—perfectly sharp and in good working condition at all times. A sharp saw will work faster, and will always do smoother and better work with less set and with less expenditure of power, than a dull one. Even to saw well is an art, which cannot be gained through the use of dull, imperfectly set, and poorly kept tools. To file well will require from the beginner close attention, a study of the subject, and careful practice, all of which can be given by any one possessing ordinary mechanical ability. If the filing is done slowly at first, care being taken to hold the file at the same angle for all the teeth, a little faithful practice will always bring success.

PLANES.

The Iron Plane. The modern iron plane, illustrated in Fig. 22, can now be bought in a great variety of sizes and styles. These planes, with their true and unchanging faces, and their simple appliances for setting and adjusting the cutter (or **plane-iron**) to the face of the plane and to the required thickness of shavings, are greatly to be preferred to the old-style wooden planes.

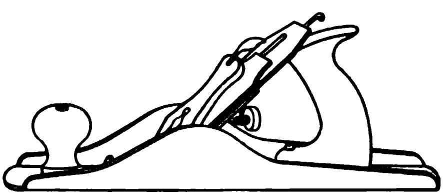


Fig. 22.

The general construction of the iron plane will be readily understood from Fig. 23, one side of the plane being removed to show the arrangement of the parts; *a* is the cutter, or plane-iron, which is made of the best cast steel and of equal thickness throughout. In all new planes this part will be found ground and sharpened for immediate use.

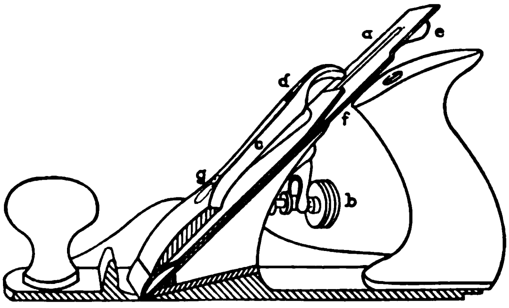


Fig. 23.

The cap-iron *f* (Fig. 23) is fastened to the plane-iron, by an adjusting screw, as shown in Fig. 24. For whetting or grinding the cutting edge, it is not necessary to remove the cap-iron,

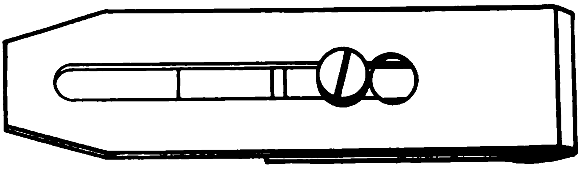


Fig. 24.

but only to loosen the connecting screw and to slide the cap back to the extreme end of the slot in the plane-iron, tightening it there by a turn of the screw. The cap-iron will then serve as a convenient handle or rest in whetting or in grinding.

The iron lever *c* (Fig. 23) is held in place below its center by the screw *g*, which acts as a fulcrum, and the lever is readily clamped down upon the irons by the use of the cam-piece *d*. When this cam is turned upward it ceases to bear upon the irons. The lever *c* may then be removed from its place, and the irons released, without turning or changing the adjustment of the screw *g*, as the lever and irons are properly slotted for this purpose.

Should the pressure required for the best working of the plane-iron need changing, it can easily be obtained by tightening or loosening the screw *g*.

When the plane-iron is secured in its place, the use of the brass thumb-screw *b* will *draw* or *drive* the plane-iron; and thus the thickness of the shaving to be taken from the work can be regulated with perfect accuracy. By the use of the lever *e*, located under the plane-iron, and working sidewise, the cutting edge can easily be brought into position exactly parallel with the face of the plane, should any variation exist when the iron is clamped down. To ascertain this, hold the plane up, and look down over its face; the greater projection, if there be any, of one or the other of the corners of the iron, can readily be seen.

The cap-iron *f*, which is not sharp, is *not*, as is often supposed, used for the purpose of strengthening or stiffening the cutting iron, but as a chip-break to prevent the cutting edge of the plane-iron from chipping, tearing, and breaking the grain of the wood below the surface when the grain turns and twists, or when it is knotty and crooked. In such cases the tendency of the plane-iron is to split and tear out the fibres of the wood in front of the cutting edge. To avoid this, the cap-iron is screwed on with its dull edge quite close to the cutting edge, so as to bend and break off the fibres or the shavings before the split gets fairly started below the surface.

The cutting edge of the plane-iron is said to have *lead* in proportion to the distance it is placed in advance of the dull edge of the cap-iron. The depth of the splits, or the roughness of the cross-grained surface, will be just equal to the lead of the cutting edge. For soft, straight-grained wood, the lead may be $\frac{1}{32}$ inch or even more, but this must be reduced in proportion as the wood is curly, cross-grained, or knotty.

The grinding, or the whetting, must always be done on the *bevel* side only of the plane-iron, the upper side being kept as flat and as smooth as possible to secure easy working.

All plane-irons should be ground slightly rounding to the extent of the thickness of a thin shaving. This rounding of the cutting edge should be the true arc of a circle throughout the entire length of the cutting edge, and not simply a rounding-off of the corners as is sometimes directed. Rounding the edge to the extent of the thickness of a shaving will prevent the plane-iron from grooving into, or plowing out a wide groove in, the surface that is being worked, and will also assist greatly in working the edges of the piece to right angles, or square with the face side. To do this it is not necessary, should one corner of the edge be higher than the other, to tilt the plane on the high edge, but, while holding it flat and firm on the surface of the edge being planed, push the plane sidewise towards the highest corner in order to reduce that corner. This will readily be understood when we remember that the cutting edge of the iron is rounding. If the plane is held so that the middle of the plane-iron will do the cutting, the shaving planed will be of the same thickness on both edges; but if the plane is pushed over to one side, either to the right or to the left, the shaving will be feather-edged, or thick on one edge and thin on the other, thus reducing the higher corner of the edge of the piece.

When the plane is to be used, the beginner should first carefully adjust it to the thickness of shaving required, by holding it up and looking down over the face of the plane, when the projection of the plane-iron can readily be seen, and then by testing on the piece to be planed.

The operator's position should be one of perfect ease, standing well back of the piece to be planed, and pushing the plane to arm's length *from* (not alongside of) the operator, taking long and continued shavings from the board. When starting the shaving at the end of the board, care should be taken to hold the forward end of the plane down firmly, or the act of pushing it forward wi cause that end to tilt up and the plane-iron to chatter on the surface as it begins to cut the shaving. This is owing to the fact that nearly two-thirds of the plane overhangs the end of the board, requiring firm pressure on the forward end to balance it while the stroke is being started.

To insure smooth work, care must be taken to plane *with the grain* of the wood, and not *against* the ends of the fibres as they lie in the surface of the board. Should the fibres tear out and the surface become rough, reverse the ends of the boards so as to cut the shaving in the opposite direction, and note the difference in the effect on the planed surface.

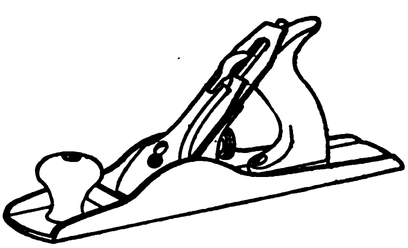


Fig. 25.

Of iron planes, the most important is the No. 5 **jack plane,** 14 inches long, and having a cutter 2 inches in width. This plane is illustrated in Fig. 25.

When the pattern lumber has first been roughly planed in a planing mill, this No. 5 plane almost exclusively can be used for planing and pattern making. In making or in "truing up" very large surfaces, however, or in making long glue joints, the No. 7 **jointer plane,** 22 inches long and having a cutter 2⅜ inches wide, will be found necessary. This plane is shown in Fig. 22, and differs from the jack plane only in its length and in its extra width of face.

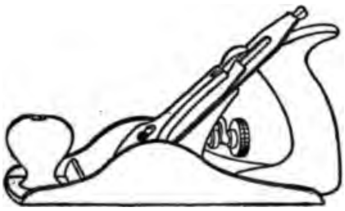


Fig. 26.

For mahogany or other hard wood, the No. 4 **smooth plane,** illustrated in Fig. 26, will be found very useful. This plane is made in several sizes. The No. 4, which is 9 inches long and has a 2-inch cutter, is the best size for general use.

Next in importance to the three planes already mentioned, is the **block plane,** illustrated in Fig. 27. The No. 19, which is 7 inches long and has a cutter 1¾ inches wide, is the most desirable for the pattern maker's use. It has an adjustable throat, as well as the screw and lateral lever adjustments of the other planes. This plane has the advantage of being so constructed as to be held easily in one hand. Owing to the low angle at which the cutter is placed it works more smoothly and easily on end wood and on miters than any other plane.

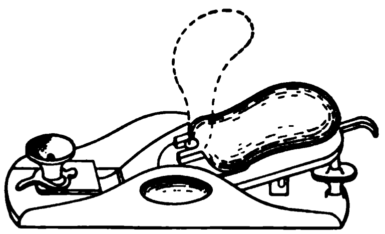


Fig. 27.

In cases where lumber must be dressed from the rough, without being first roughly dressed in a planing mill, the No. 40 **scrub plane,** illustrated in Fig. 28, will be almost indispensable. It is 9½ inches long, and has a cutter 1¼ inches wide. The cutter is a single iron, and is ground and sharpened very rounding on the cutting edge, as shown in Fig. 28, to allow of cutting a very thick shaving without grooving at the edges. This plane works rapidly and easily, preparing the rough-sawn surfaces of planks for the finishing planes.

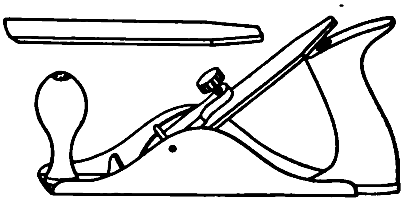


Fig. 28.

For truing and smoothing circular arcs and curves of all kinds, either convex or concave, there is no tool that equals the **circular plane,** illustrated in Fig. 29. This plane has a flexible steel face which can easily be shaped to any required arc or curve by turning the knob on the front of the plane.

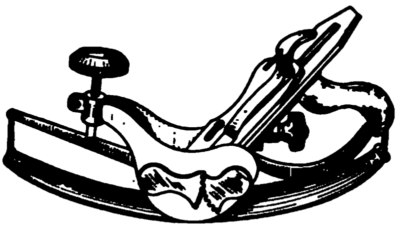


Fig. 29.

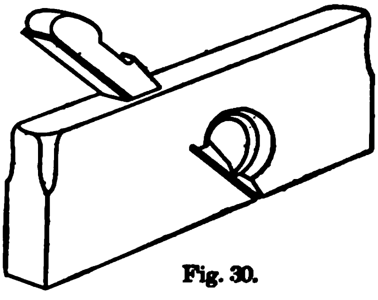


Fig. 30.

The Rabbet Plane. Among the special planes used by the pattern maker, the rabbet plane, illustrated in Fig. 30, is the most important. The face of this plane is always flat and at right angles to the sides. It is used in working out square angles and corne or *laps* as they are called in carpentry, and also for working lap joints, as shown in Fig. 31.

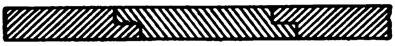


Fig. 31.

The skew-iron rabbet plane, in which the cutting edge of the plane-iron is set diagonally across the face of the plane, works much more smoothly and easily than one in which the iron is set at right angles to the side of the plane. The improved rabbet plane shown in Fig. 32 is fitted with depth gauge, and also with a spur cutter, both of which are often of great convenience to the workman.

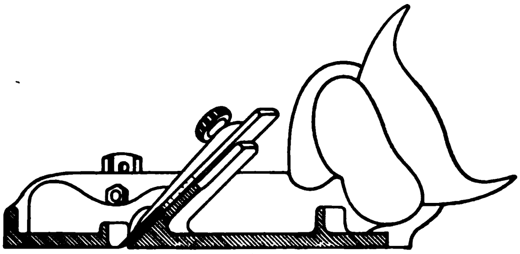


Fig. 32.

Rabbet planes are made in sizes ranging from $\frac{1}{2}$ inch to $1\frac{1}{2}$ inches in width. The 1-inch and $1\frac{1}{4}$-inch are convenient sizes for general work.

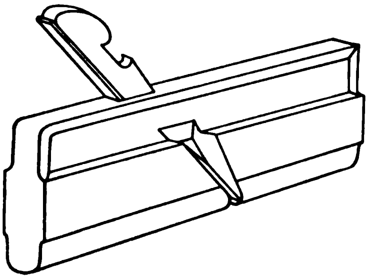


Fig. 33.

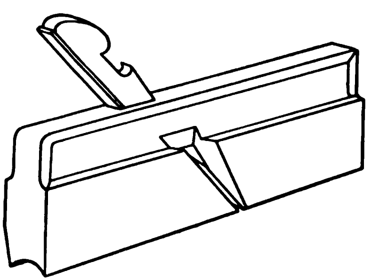


Fig. 34.

Round and Hollow Planes. These planes are illustrated in Figs. 33 and 34. They are made of different curvatures, and a set of assorted sizes, especially the *rounds*, are almost indispensable to the pattern maker for finishing semicircular core boxes, for making fillets, and for working out curves of every description, both concave and convex.

The Core-Box Plane. The core-box plane, shown in Fig. 35, while not indispensable, will be found to be a very rapid working and useful tool for making semicircular core boxes up to 2½ inches in diameter. By using the extension sides, one of which is shown in the illustration, and two pairs of which are always furnished, this tool will work accurately a concave semicircle up to 10 inches in diameter.

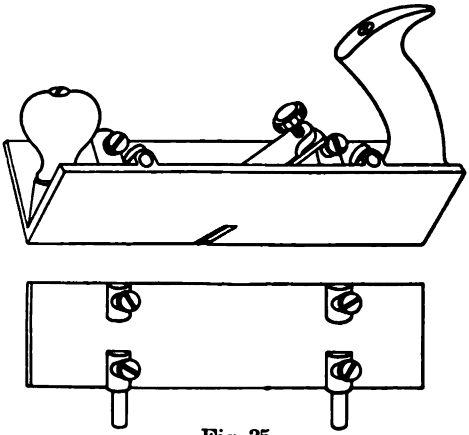


Fig. 35.

The core-box plane is constructed upon the principle that if the sides of a right angle lie upon the extremities of a diameter of a circle, the vertex of the right angle will lie upon the circumference of the circle. This is illustrated in Fig. 36, from which it will be seen that if the block of wood has been worked to a perfect semicircle, and the edges of the blades of a try-square or right-angled triangle touch the semicircular curve at its extremities, the right angle or corner will touch the arc at some point, as *b*, *e* or *h*, the angles *abc*, *def*, and *ghi* all being right angles.

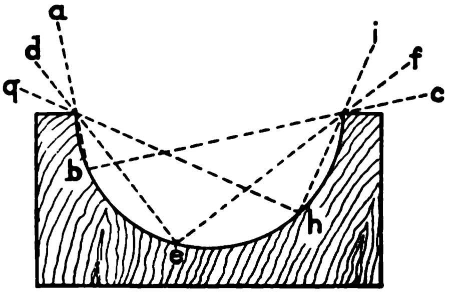


Fig. 36.

To this kind of plane the objection is often made that it abrades and wears off the corners of the semicircle as it is being worked out. This, however, can be practically avoided if the following instructions are followed:

Carefully lay out the block from which the core box is to be worked, from a center line on the face of the block, describing on each end of the block a semicircle of the required radius; connect the extremes of the two end arcs by straight lines on the face of the block, as shown in Fig. 37. Two very thin strips of hard wood are tacked along these lines, just outside of the wood to be cut away, as shown at *a* and at *b* in Fig. 38. These strips form rests for the sides of the plane while the heavier part of the work is being done. After working out the semicircle as far as the strips will allow, as shown by the dotted arc *acb*, the strips are removed, when the work can be finished without materially affecting the corners at *a* and *b*.

When making the finishing cuts with this plane, care must be taken to adjust the cutter centrally, *i. e.*, so that it will cut equally to both right and left; otherwise the work will not be correct. If, however, the work has been done with care, the finishing may be completed with coarse, and lastly with fine, sandpaper held on a cylindrical block of radius slightly less than that of the required core box.

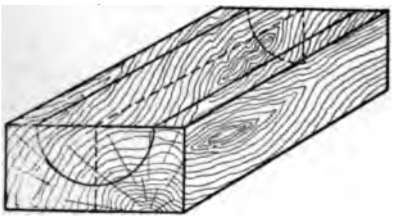


Fig. 37.

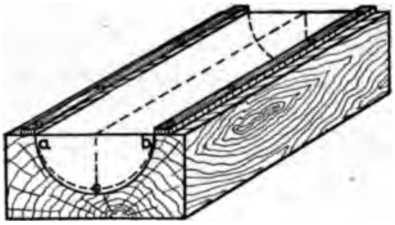


Fig. 38.

The Router Plane. This tool will be found very convenient for smoothing out sunk panels, for letting in rapping and lifting plates, and for all depressions below the general surface of the pattern. It will plane the bottoms of recesses to a uniform depth from the surface of the work, and will work into angles and corners that otherwise could be reached only by the use of the paring chisel. It is illustrated in Fig. 39.

The Spoke-Shave. The spoke-shave is used by the pattern maker for shaping and rounding out small curves either convex or concave, which cannot be reached with the circular plane. It can be found in a great variety of styles, either in metal, as shown in Fig. 40, or in wood. The all-wood boxwood spoke shave illustrated in Fig. 41, without brass facing or screw adjustment, is to be preferred to all others for the pattern maker's use, especially for working pine or other soft wood.

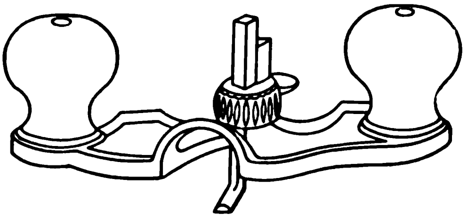


Fig. 39.

CHISELS AND GOUGES.

The chisel enters so largely into the work of the pattern maker in paring and shaping patterns that the quality of the tool should

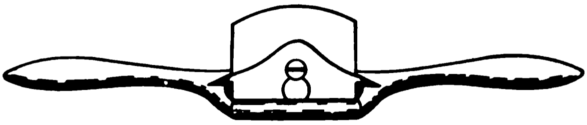


Fig. 40.

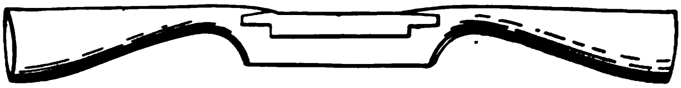


Fig. 41.

be of the best. While carpenters' chisels are made in several styles, they may be divided into two general classes, **socket-handled chisels**, and **firmer** or **paring chisels.** The former are illustrated

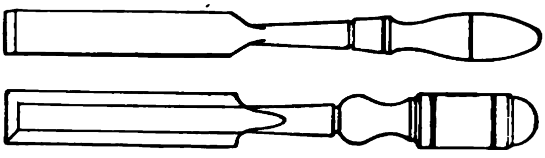


Fig. 42.

in Fig. 42, and are used for framing, and for very heavy work of all kinds in which the use of a mallet is necessary. The common firmer or paring chisels, two styles of which are shown in Fig. 43, are the best all-round chisels for pattern work. Being lighter and thinner than the others, they are better adapted to the light work on which they are used; moreover, when used with care, they will answer every desired purpose, even for heavy work or with a mallet.

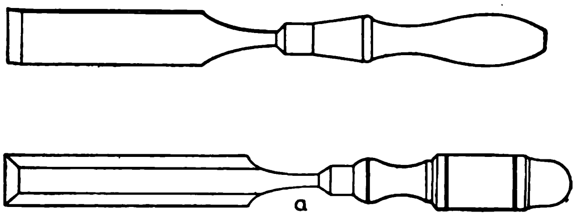


Fig. 43.

The beveled-edge chisel shown at *a*, Fig. 43, is greatly to be preferred. It is lighter than the other kind illustrated, and the square angle being removed, the workman is enabled to reach into angles and under projections difficult to reach with a square-edged tool. A set varying in width from $\frac{1}{8}$ inch to $\frac{5}{8}$ inch by eighths, and from $\frac{3}{4}$ inch to $1\frac{1}{2}$ inches by quarters, nine chisels in all, will be found useful.

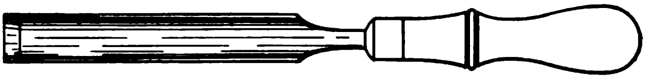


Fig. 44.

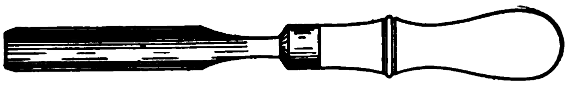


Fig. 45.

The paring gouges used in pattern making are ground or beveled on the inside, as shown in Fig. 44. These gouges are made in **regular, middle,** and **flat** sweeps. They are indispensable for working out core boxes and other curves.

In selecting a set of paring gouges, they should be not only of assorted sizes, but of different sweeps, so as to work out semicircles and curves of different radii.

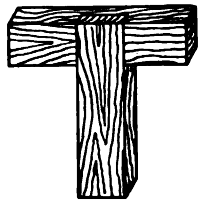


Fig. 47.

The common firmer gouge, illustrated in Fig. 45, is a useful tool for rough or heavy work, but in general its use can be dispensed with in pattern making.

The manner in which the chisel is used is so obvious and simple that any instruction in that direction would seem unnecessary. We shall only say in a general way that in using a chisel on a flat surface or in a recess it should always be held with the flat or back of the chisel against the work; and, whenever possible, it should not be pushed straight forward or straight through an opening, especially when paring across the grain of the wood, but should be moved laterally at the same time that it is pushed forward, as indicated by the dotted lines in Fig. 46. This insures a shearing cut, which, with care, even when the material is cross-grained, will produce a smooth and even surface.

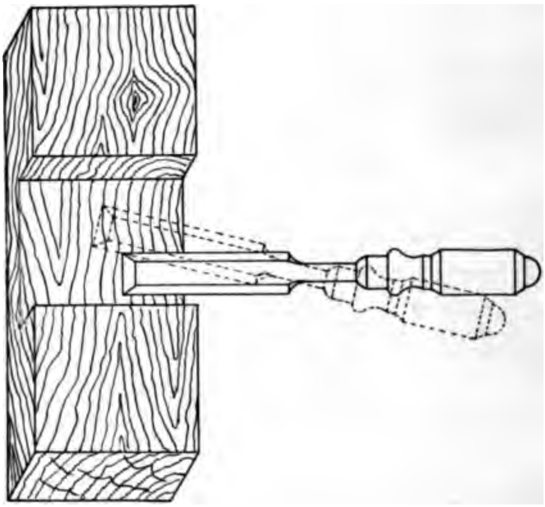


Fig. 46.

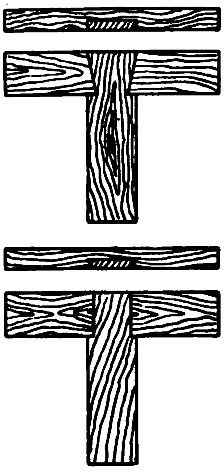


Fig. 48.

As an exercise for acquiring the free use of the paring chisel, there is nothing better for the beginner than the simple half-lap joint shown in Fig. 47.

The shoulders or the ends of the openings must be cut with a back saw. The opening is then cut out and the shoulders smoothed with a wide chisel, and a perfect fit obtained by continued trials.

The two dove-tail joints shown in Fig. 48 may be attempted, after having succeeded with the half-lap; and these exercises should be continued by the student until such control of the chisel is attained that this and similar work can be done with ease and certainty. For laying out work of this kind the blade of a pocketknife or bench knife should always be used. This gives a clean, sharp-cut angle for the meeting sides of the joints, which cannot be obtained if a scratch-awl is used. The awl tears and breaks the fibres of the wood, producing a rough, ragged angle, which, on fitting, cannot produce a smooth and close piece of work. A pencil is equally objectionable because of the indefinite dimensions given by its use.

An assortment of four to nine carver's gouges, **front bent** as shown in Fig. 49, will be found necessary for working out short, deep curves, and in places where a straight gouge cannot be used, as in the core boxes for a globe valve, shown in Figs. 222, 223, 227, 228, and similar work.

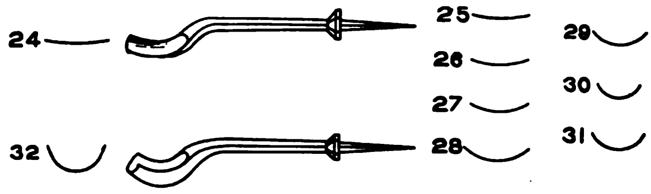


Fig. 49.

The full set consists of *nine* tools, the curves of which are numbered from 24 to 32. The two extremes, Nos. 24 and 32, are shown in Fig. 49, and also the shapes of the curves of the seven intermediates, Nos. 25 to 31 inclusive.

If desired, to save expense, each alternate tool might be omitted from the set, only the odd numbers 25, 27, 29 and 31 being selected. For ordinary work these will be found sufficient.

SQUARES.

The best try-squares are now made with graduated blades, Fig. 50, and from two inches to twelve inches in length of blade. Several sizes will be found necessary, as in many cases the blade must be short to admit of its application in pattern work.

The adjustable try-square, illustrated in Fig. 51, is not expensive, and will be found to fill the requirements of several small squares. It is made in two sizes, with graduated blades four inches and six inches in length respectively. The blade of this square can be firmly secured in its seat at any point. When the blade is carried entirely to the front of the handle, it is like an ordinary try-square; and the moving of the blade makes the square equally perfect down to one-quarter-inch length of blade, or even less.

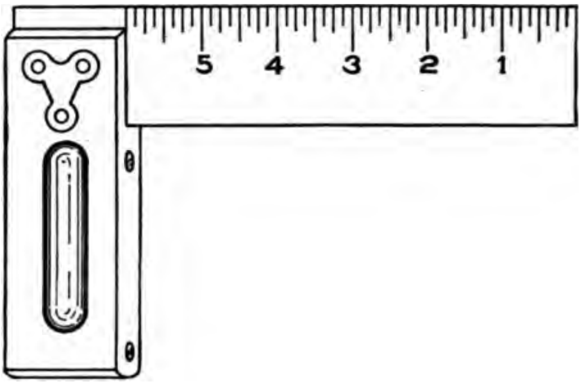


Fig. 50.

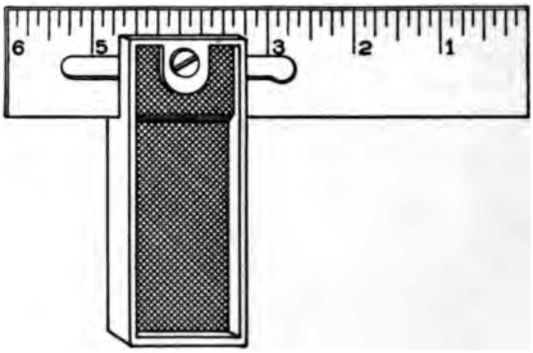


Fig. 51.

With one adjustable square of this kind, six inches in length, only one 8-inch or one 10-inch ordinary square will be found necessary.

A still more convenient, but slightly more expensive, form of adjustable try-square is shown in Fig. 52. It differs from that shown in Fig. 51, in being self-contained, no screw-driver being necessary for moving the blade or securing it in position, and also because the blade can be removed entirely, and an extra blade, shown in Fig. 53, substituted. The ends of this second blade give both the hexagon and octagon angles, which is a matter of great convenience to the pattern maker. Fig. 53 shows the hexagon end of the blade applied. Reverse the blade and the octagon end will be in position for use.

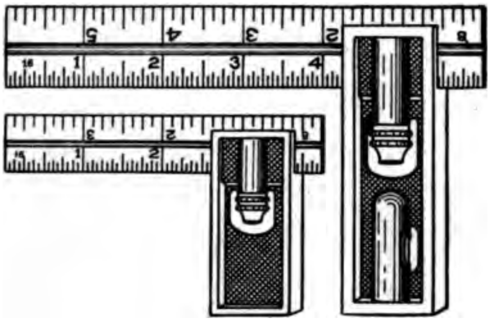


Fig. 52.

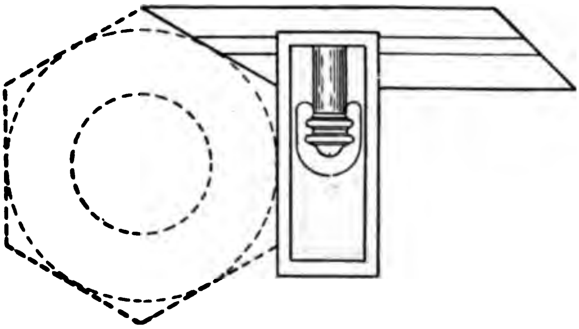
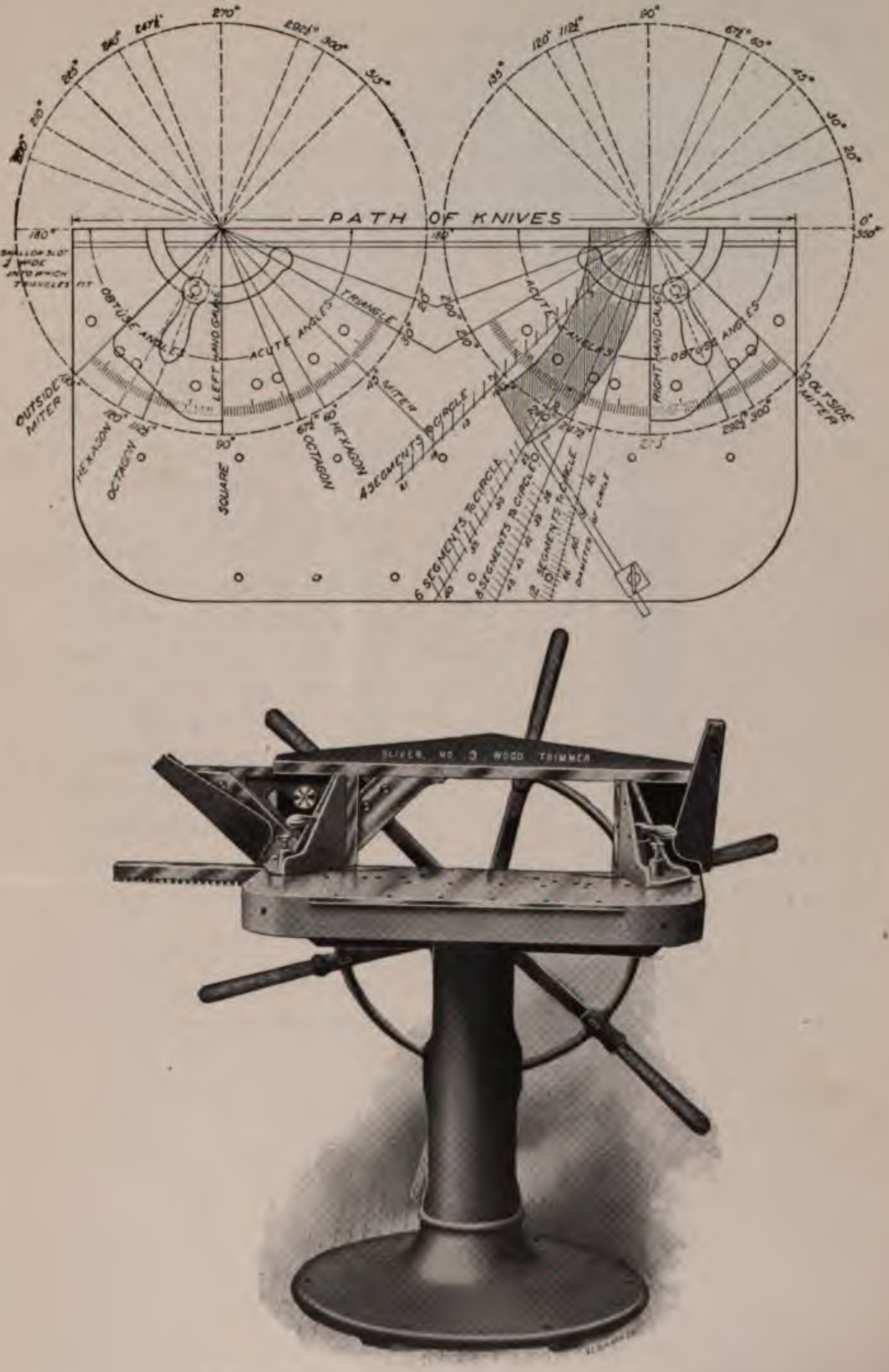


Fig. 53.

To the above try-squares there should be added a carpenter's steel square 24 inches × 18 inches, for use in laying out and squaring up large stock and large patterns.



UNIVERSAL TRIMMER, SHOWING GRADUATIONS.
Oliver Machinery Company.

BEVELS.

The bevel illustrated in Fig. 54, with the clamping screw in the end of the handle, is the most accurate and the most easily adjusted style of this indispensable tool. The blades are made from 6 to 12 inches in length, and have a slot in one end, which admits of that end being shortened to meet the requirements of work.

The small **Universal bevel,** illustrated in Fig. 55, like the adjustable try-square, is not an expensive tool, and will be found generally useful, especially in working the draft on patterns, and in turning the parts of patterns on the wood lathe which cannot be reached with an ordinary bevel. The *set-off* in the blade increases its capacity and usefulness, so that any angle, however slight, can be obtained.

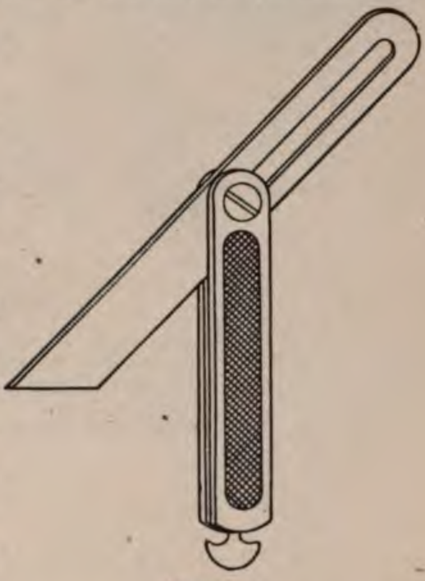


Fig. 54.

One 3-inch *Universal*, and one 8-inch or 10-inch ordinary bevel, will meet all the requirements of the pattern maker for the beveled edges and surfaces and the draft of pattern work.

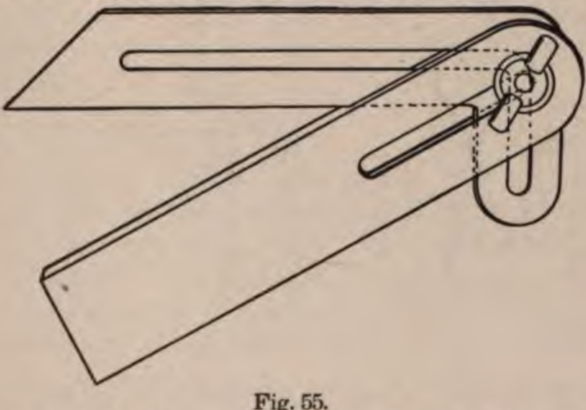


Fig. 55.

MARKING GAGES.

The marking gage is used for drawing a line at a given distance from, and parallel to, the already trued and jointed surface or edge of a board or piece of wood that is being marked to dimensions. There are many forms of this tool, but in the "Improved Marking Gage," illustrated in Fig. 56, the head is reversible. The flat side of the head is used for ordinary straight work, while the reverse side, having the brass face with two projecting ribs, enables the operator to run a gage line with perfect steadiness and accuracy around curves of any radius, either convex or concave —a feature much to be desired in a pattern-maker's gage.

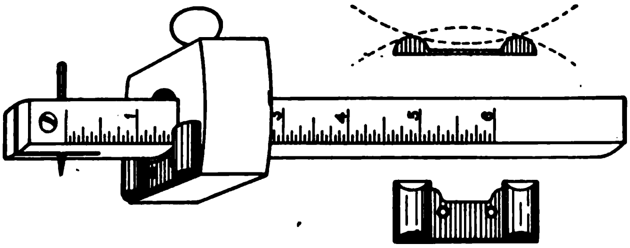


Fig. 56.

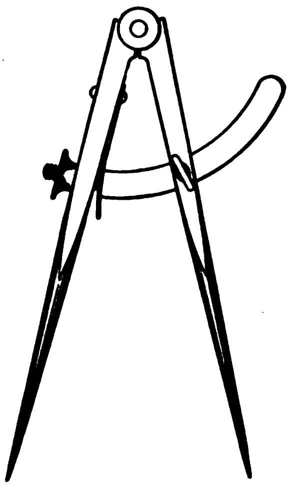


Fig. 57.

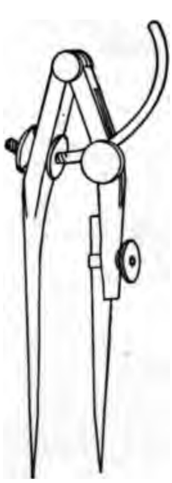


Fig. 58.

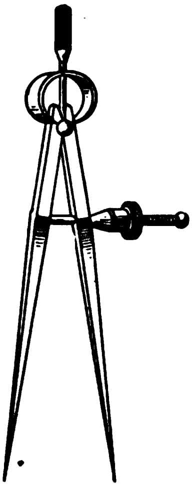


Fig. 59.

DIVIDERS AND TRAMMELS.

The ordinary wood-worker's dividers can be bought in many forms, the most common being the **screw-adjusting wing dividers,** shown in Fig. 57. This form is reliable, and is easily adjusted to the required distance between points. Moreover, when clamped by the thumb-screw, it is not liable to be altered by a slight blow in handling.

Another and improved form is shown in Fig. 58, one leg of which is removable so that a pencil can be inserted. This will be found very convenient for marking and laying out work.

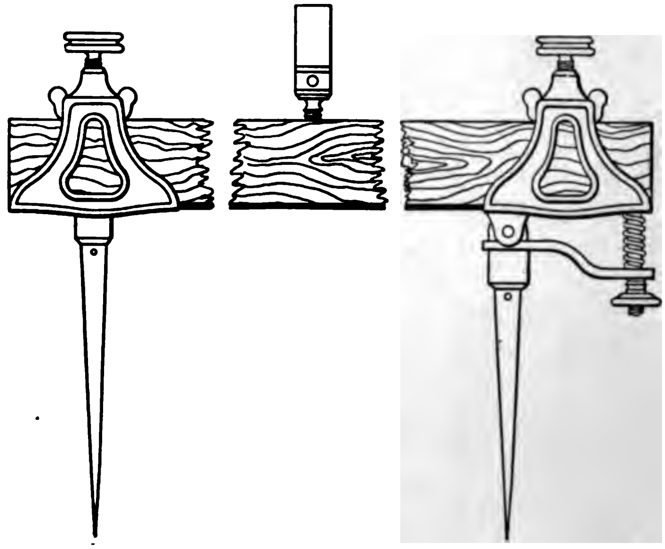


Fig. 60.

For spacing the teeth of gear wheels, and for other work in which great accuracy is required, a pair of 2½-inch or 3-inch dividers, such as are shown in Fig. 59, will be found necessary.

The **trammel** is used when the distance between the points to be reached is too great for the ordinary dividers. The trammel points are clamped to a beam of sufficient length to enable them to be set to the required distance apart. They may be bought with one adjustable point, as illustrated in Fig. 60; or without the screw adjustment, as in Fig. 61. The points are removable for the insertion of a pencil socket and pencil when needed.

For very accurate work, an excellent tool of this kind is illustrated in Fig. 62. The beams furnished are 4 inches and 13 inches in length. By the use of the cone center, shown at V, which may be substituted for the regular point, the tool can be used for scribing a line around any hole already bored—which is sometimes a matter of great convenience. The complete set includes the pen, pencil, straight and bent points, and the cone center, as shown in the cut.

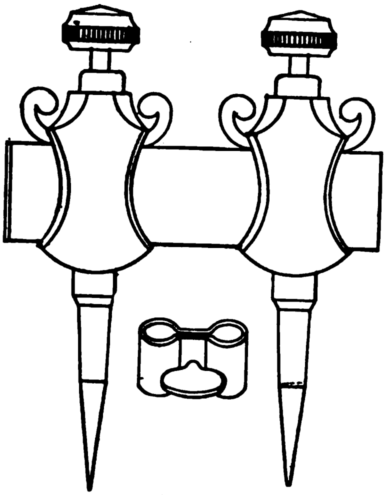


Fig. 61.

CALIPERS.

Calipers, like dividers, are made in many different forms, with and without screw adjustment. Fig. 63 illustrates the screw-adjusting wing calipers for outside measurements; and Fig. 64 the firm-joint outside calipers, used for the same purpose.

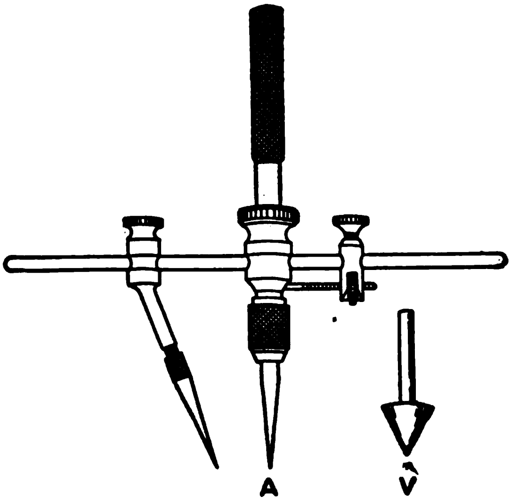


Fig. 62.

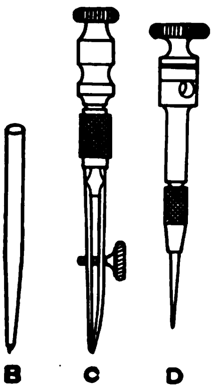


Fig. 62A.

Inside calipers for taking inside dimensions and inside distances are shown in Fig. 65.

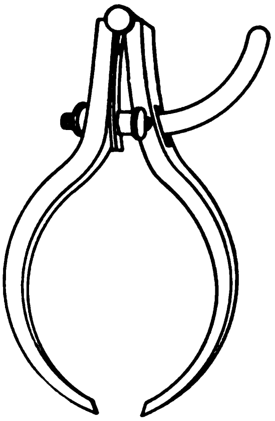


Fig. 63.

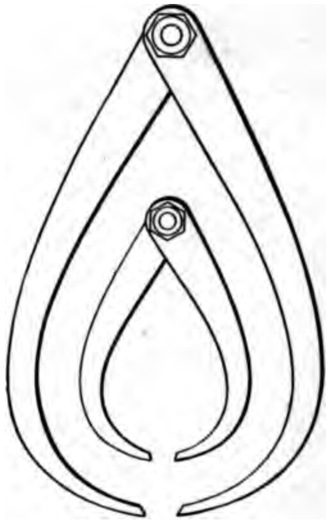


Fig. 64.

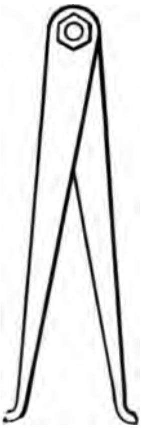


Fig. 65.

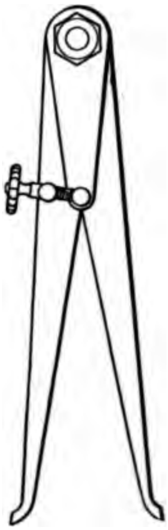


Fig. 66.

The adjustable inside calipers are illustrated in Fig. 66.

Calipers are used for measuring the distances between points, external and internal, when a rule could not be used with accuracy.

They are indispensable to the wood turner for measuring the diameters of cylindrical forms and other work while being turned to required dimensions in the lathe. When used by the pattern maker, they may be applied while the wood is revolving, until it has been reduced almost to the required dimensions; after which, when the calipers are used, the lathe should be stopped, to prevent the surface from being marked by the points, and in order to obtain exact measurements.

The calipers should not be pushed or forced over the piece, but in passing over the finished cylinder, the points should touch it lightly without springing the legs of the calipers; otherwise the required dimensions cannot be obtained with accuracy.

MISCELLANEOUS TOOLS.

There remain to be described a few tools, which, while necessary, are so common as hardly to require either illustration or description. Among these are the **hammer,** the best form of which for the pattern maker is shown in Fig. 67, and the **mallet,** of which the best form is shown in Fig. 68.

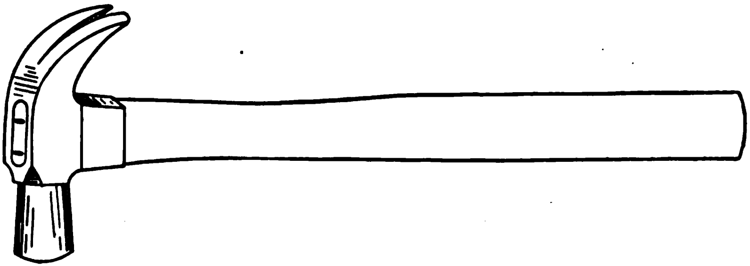


Fig. 67.

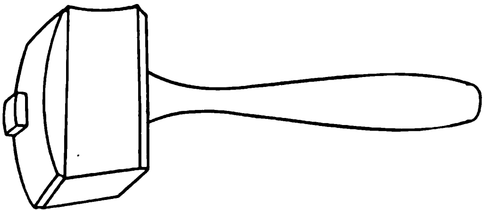


Fig. 68.

A mallet that is to be used on the handle of firmer chisels and other pattern maker's tools, should not be made of hickory or of num-vitæ, nor have hard-rubber or hard-fibre facing. Mallets us made soon mar, splinter, and destroy the tool-handles on which they are used. Beechwood and maple furnish the best material for mallet-heads for the use of the woodworker who works in pine and other soft woods. It is true that the mallet-head will not last so long if made of beech or maple wood; but the chisel and gouge handles will be protected, which is a matter of much greater importance.

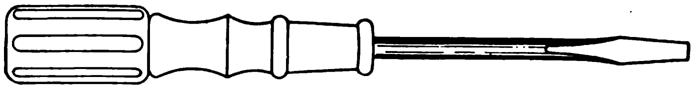


Fig. 69.

Of the **screw-driver,** illustrated in Fig. 69, at least two or three sizes will be found necessary.

The **scratch-awl,** Fig. 70, although used but little at the work-bench (a knife being used in its place for all accurate markings), is indispensable to the pattern maker for laying out the dimensions on his work while it is revolving in the turning lathe. It should be long and slender, as shown, and is used on the revolving wood by placing it over the required graduation of the rule, while the latter is held on the tool rest.

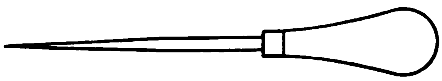


Fig. 70.

Brads and small wire nails must often be driven at such an angle to the grain of the wood, or in such a position, as to make it necessary first to bore a small hole in order to start the brad in the required direction. The brad-awl, illustrated in Fig. 71, is a convenient tool for this purpose. It is commonly ground to a chisel point, as shown at *a*, but will be less liable to cause splitting, and will work faster and with greater ease, if ground to a double spear point, as shown at *b*. The four corners, if kept sharp, will enter the wood and cut faster than the chisel point.

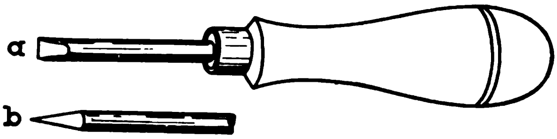


Fig. 71.

Side-cutting **pliers,** such as are illustrated in Fig. 72, will be found convenient not only for cutting off wire and brads, but for removing small brads and for holding small pieces while being worked to shape.

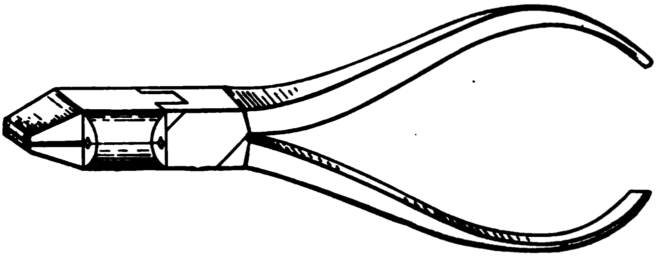


Fig. 72.

Among the tools which cannot be dispensed with are the **brace** and an assortment of **boring bits.** The most desirable style of brace is the **ratchet brace,** illustrated in Fig. 73. The convenience of the ratchet will soon be apparent from the necessity, so often arising, for boring holes or driving screws (with the brace) in angles or close to projections where the full sweep of the brace cannot be taken. Braces are made in many sizes, with sweep varying from 6 inches to 14 inches in diameter.

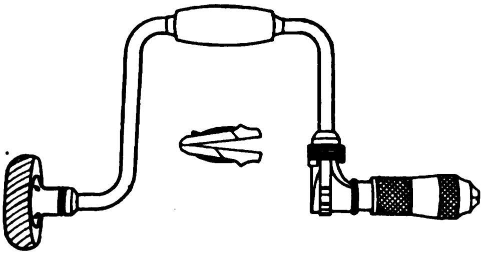


Fig. 73.

A brace with an 8-inch sweep is the most convenient in size for boring holes one inch or less in diameter in soft wood. For larger holes, and especially in very hard woods, a 10-inch or 12-inch sweep will be necessary.

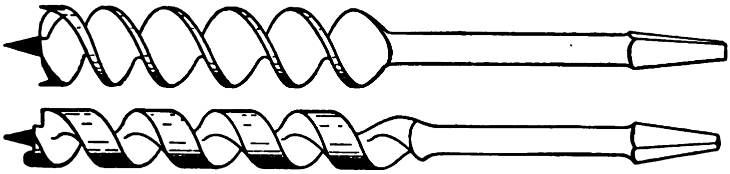


Fig. 74.

Wood-boring bits are made in many styles. The most important are the auger bits, two styles of which are shown in Fig. 74.

They can be bought in sizes running by sixteenths of an inch from ¼ inch to 1 inch. For holes larger than one inch, the **No. 2 extension bit,** shown in Fig. 75, is the best. It has two cutters, and will bore a hole of any size from ⅞ inch to 3 inches in diameter.

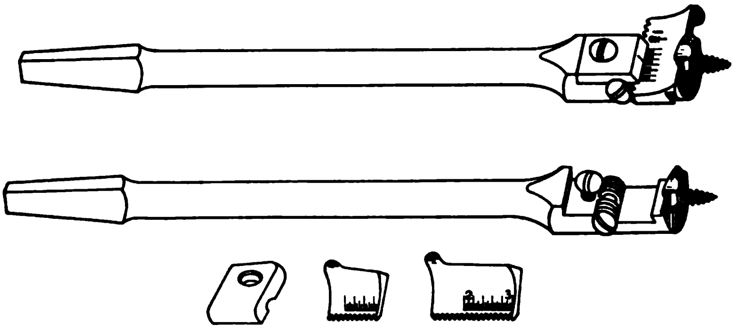


Fig. 75.

For screw-holes, the **gimlet bit** or the **twist drill** for wood, both of which are illustrated in Fig. 76, can be bought in all sizes running by thirty-seconds of an inch from $\frac{1}{32}$ inch up to ⅜ inch.

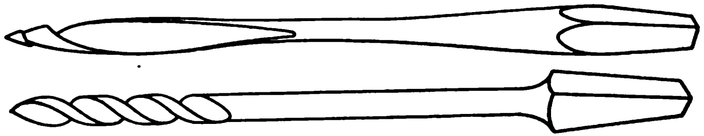


Fig. 76.

The **brace screw-driver,** and also the **brace countersink** for screw-heads, are important tools. They are shown in Fig. 77, and can be bought in large, medium, and small sizes.

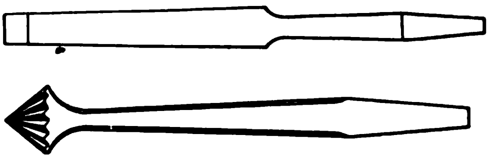


Fig. 77.

The half-round **cabinet file** and half-round **cabinet rasp,** shown in Fig. 78, enter largely into the work of the pattern maker, and should be bought in sizes each of 6 inches, 8 inches, and 10 inches. Larger as well as intermediate sizes may often be found necessary, but will not be needed for ordinary work.

Every pattern shop should have at least one dozen each of three or four different sizes of **hand-screws** or **clamps** similar to that shown in Fig. 79. These are adjustable through wide ranges. They are used for clamping together the material that is being glued up to form the different parts of a pattern, and are convenient also for many other purposes. The all-iron C clamp, shown in Fig. 80, is sometimes useful in positions that are hard to reach with a hand-screw. The method of adjusting and of using the hand-screw will be fully explained later.

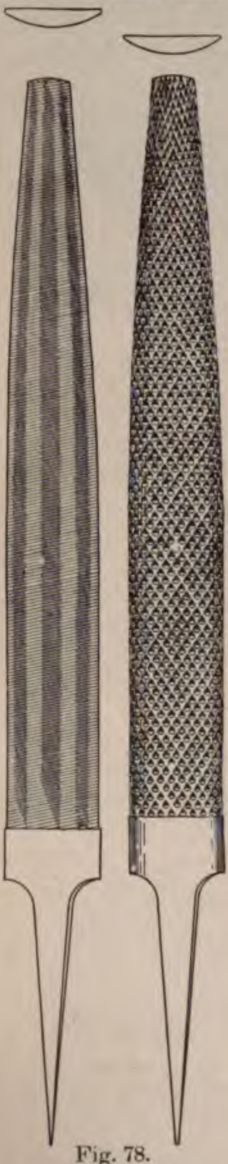


Fig. 78.

RULES.

For all ordinary measurements, a 2-foot, folding **standard rule,** Fig. 81, will be sufficient, but this rule must not be used for laying out or for working patterns, or any part of a pattern or core box, to the required dimensions. For all such purposes a **shrinkage rule** must be used. The reasons are that when a mould made from the wooden pattern in the sand is filled with molten metal, its temperature is very high, and as it cools and solidifies it contracts. Accordingly, to compensate for this, the pattern maker must add to the size of the pattern. In order that this may be done, and exact relations nevertheless be maintained for all dimensions, a shrinkage rule is used. This rule is marked off exactly like an ordinary rule; but if the two are compared, the shrinkage rule will be found to be about $\frac{1}{8}$ inch longer than the other for each foot of length.

The contraction or shrinkage of different metals in the moulds varies greatly, that for cast iron being, as above stated, $\frac{1}{8}$ inch to each foot. For brass, however, the shrinkage is $\frac{3}{16}$ inch to the foot; and for many of the softer metals it is as great as ¼ inch per foot. Shrinkage rules, Fig. 82, are usually made of a single piece

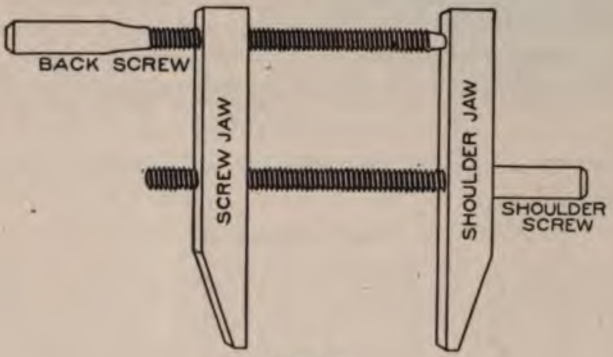


Fig. 79.

of boxwood or beech, those for cast iron being 24¼ inches long, for brass 24⅜ inches long, and for other soft metals 24½ inches

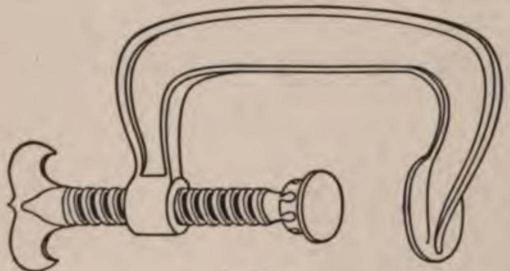


Fig. 80.

in length. They can also be bought made of tempered steel 12⅛ inches, 12$\frac{3}{16}$ inches, and 12¼ inches in length. In making use

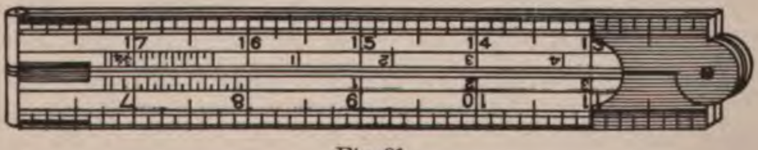


Fig. 81.

of the shrinkage rule, the workman will proceed just as though he were using a standard rule; and when the pattern is completed it will be found to be larger in all its dimensions, just in proportion as the extra length of the shrinkage rule makes it greater than the standard rule

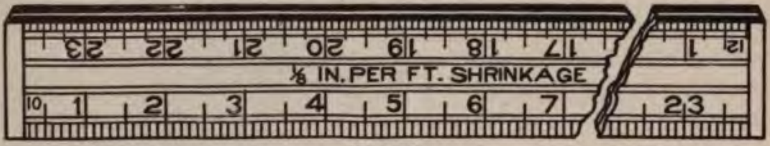


Fig. 82.

OIL STONES.

As before stated, new planes, chisels, and other edged tools, if of the best quality, are always sold ground and sharpened, ready for use. When used, however, they soon become dulled, and must then be resharpened, and be so kept as to have a smooth, keen cutting edge, in order to do good work and to work rapidly. The method employed for doing this is the same for all edged tools, whether ground and sharpened on one side or on both sides.

Oil stones are used for plane-irons, chisels, and all flat and straight-edged tools; and **oil slips,** having rounded edges, for gouges, and for all tools having curved edges. They are made of different sizes, and may be found of many and widely different qualities. The best known and most widely used oil stones in this country, and perhaps in the world, are the "Washita," of which the "Lily White Washita" brand, being carefully selected, are the most even in grade and quality, and are the best-adapted natural stone for woodworkers' tools.

The Arkansas oil stones are claimed to be the hardest and finest oil stones in the world. They are composed of nearly pure silica in the form of minute crystals interpenetrating one another, and differ from the Washita only in the minuteness of the crystals and in their more compact arrangement. They are consequently very much harder and cut hardened steel more slowly than coarser grades of stone, but impart a finer and smoother edge to the tool. They are used by wood-carvers, engravers, watchmakers, and others using tools that require a very fine edge or point. They are expensive, and should be used carefully with equal parts of sperm oil and glycerine.

For wood turners' and pattern makers' tools, the sharpening qualities of the "Washita" are unsurpassed; but the quality differs greatly in stones sold under this name, some being uneven in hardness, and some soft and worthless. No trouble will be found, however, if some good selected brand such as the one mentioned above is chosen. A good size for an oil stone is 6 inches to 8 inches in length, and from 1⅝ inches to 2 inches in width. The thickness does not matter, but the stones usually vary from ¾ inch to 1¼ inches in thickness.

The oil slip should be about 4½ inches in length, and from 1¾ inches to 2 inches in width, tapering from ⅝ inch on one edge to $\frac{3}{16}$ inch on the other, both edges being rounded as shown in Fig. 83.

In using the oil stone, care should be taken to *hold the bevel of the tool flat, or nearly flat, on the stone*, so that the cutting edge may be kept thin and in easy working condition. The stone is held stationary on the work-bench, and the tool is moved forward and backward over its face. In the use of the oil slip, on the other hand, the tool is held stationary, with the cutting edge or end up, and the slip is rubbed over the beveled surface with a circular motion or stroke, until a keen, sharp edge has again been imparted to it. An abundance of oil should always be used in order that a finer and smoother edge may be given to the tool, and the pores of the stone be kept clean and free from glazing.

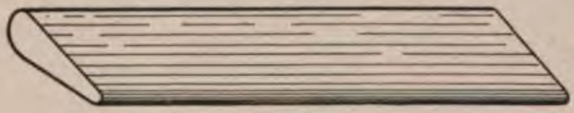


Fig. 83.

In the last few years an entirely new variety of oil stone and oil slip has been placed on the market. It is called the **India oil stone,** and is made from corundum, the hardest of all mineral substances except the diamond. These stones have wonderful cutting qualities, and differ greatly from other oil stones in that they cut steel much faster, impart better edges, and do not glaze. They are also of uniform texture throughout. India oil stones are furnished in three grades—coarse, medium, and fine—and in all required shapes, a few of which are shown in Fig. 84. Only the "fine" stones are adapted for woodworking tools and for those classes of tools requiring a fine cutting edge.

GRINDSTONES.

Second in importance to a good oil stone is the grindstone, power-driven if possible. It should not be too close-grained. A rapid-cutting stone, even if moderately coarse, is greatly to be preferred, as all ground edges must be finished on the oil stone however finely they may have been ground on the grindstone.

A stone about 36 inches in diameter when new, is a good size; and can be bought with a suitable cast-iron trough underneath, and also with an arrangement for supplying the water necessary to keep the stone wet.

In all stones there will be found great differences of hardness in different parts. Stones soon lose their cylindrical shape and must be turned true. A piece of gas-pipe or an old file will be found excellent tools for this purpose, but they must be used without water.

In using the grindstone for plane-irons, chisels, and other tools that must be ground with a long bevel, or to a thin edge, it is better to stand so that the stone runs toward the cutting edge of the tool, as shown in Fig. 85. This position grinds the tool much faster, and less of a feather will be turned up on the final edge.

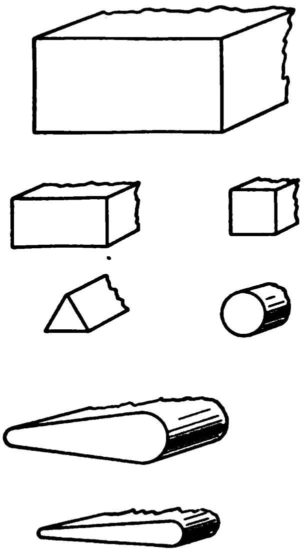


Fig. 84.

Scraping tools, however, and indeed all tools having a very short bevel, or whose edges are ground to a very obtuse angle, may he held so that the stone will revolve away from the cutting edge of the tool, this position being less liable to cut hollows in the face of the stone. This method of grinding, however, is too slow for tools having a long bevel, and which for that reason require more grinding.

When to use the grindstone is a question that often occurs to the beginner, who sometimes confuses the use of the grindstone with that of the oil stone. The grindstone is not in any sense an instrument for *sharpening* woodworkers' tools. When a chisel or a plane-iron has been sharpened on the oil stone for several successive times, the bevel is gradually worn shorter, and its shape changed from that shown at *a*, Fig. 86, to a shape similar to that shown at *b*. When the length of the bevel is thus reduced, the angle of the cutting edge is too obtuse to do good work, or to work easily. The metal at *c* must then be ground off on the grindstone, and the bevel of the tool restored to its former correct shape as shown at *a*, after which the cutting edge must be sharpened and finished on the oil stone.

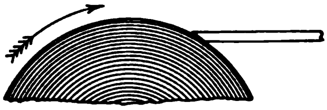


Fig. 85.

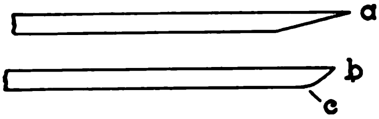


Fig. 86.

LATHES.

Of all power-driven machines, the most indispensable to the pattern maker is the **wood turning lathe.** In a small shop where small patterns only are made, a 14-inch or a 16-inch speed lathe, such as is shown in Fig. 87, may prove sufficient for all purposes; but if only one lathe can be afforded, it should be a regular pattern-maker's lathe, similar to that illustrated in Fig. 88.

The latter differs from the speed lathe in that the head-stock spindle extends through the left-hand bearing, and is fitted to receive face-plates and chucks, the same as on the inside end.

The arrangement of the countershaft is also such as to give a much wider range of speed to the lathe head, so that pieces of very large diameter may be turned at a speed proportioned to their sizes. These lathes are also fitted with a hand-feed slide rest —either compound, as shown in the illustration, or a plain sliding tool-holder moved by a rack and pinion, as may be desired. The tail stock is so arranged as to be adjustable for turning long cylinders, either tapering or straight, as may be required. When not in use the slide rest may be removed from the lathe, and the ordinary tool rest and rest socket substituted in its place for hand turning.

The speed at which a lathe should be run is always indicated by the manufacturer, the countershaft usually running at a speed of 500 to 550 revolutions per minute.

A variety of **chucks** and **face-plates,** used for holding the work, are always furnished with a lathe. Some of these are shown in the engraving, the **screw chuck** being shown at *a*, Fig. 88; and two of the iron face-plates are shown, one on each end of the spindle.

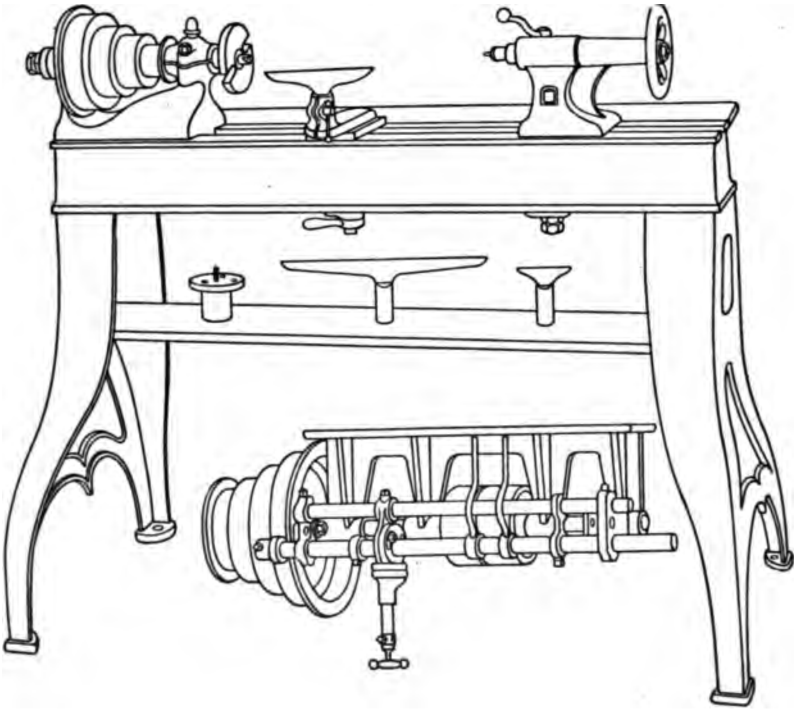
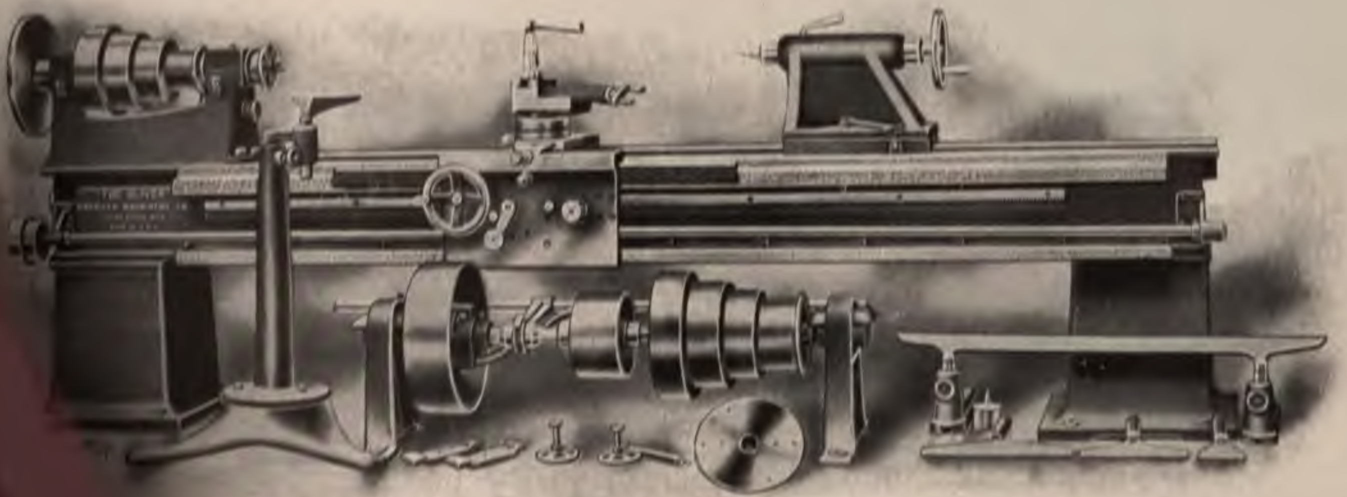


Fig. 87.

But in addition to these face-plates, which really form the base only for chucking the pattern, **wooden chucks** must be used intermediate between the iron face-plate and the pattern. These wooden face-plates are constructed in a variety of ways by different pattern makers; but for small patterns it is necessary to



WOOD LATHE.
Oliver Machinery Company.

use only a plain board $\frac{7}{8}$ inch to $1\frac{1}{4}$ inches in thickness and of a slightly greater diameter than the required pattern. This board is screwed fast to the iron face-plate as shown in Fig. 89, to which, after being placed in the lathe and turned true, the pattern is attached, as will be fully illustrated and described farther on. For

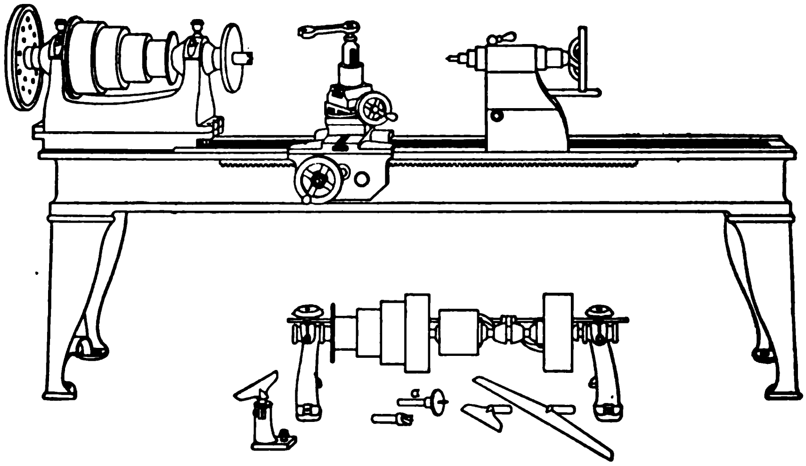


Fig. 88.

patterns of a medium size, say 20 inches to 30 inches in diameter, the board should be stiffened by means of a wide wooden bar firmly screwed across the back, as in Fig. 90.

When chucks are needed for very large or heavy work, the chuck, in order to prevent vibration, must be strong in proportion. It is best made as illustrated in Fig. 91, in which the front of the chuck, as shown at *a*, will be least affected by the moisture in the air if left unglued, or at best only tongued and grooved, being held together by the cross-bars only, as shown at *b*, to which it is firmly screwed, without glue. This chuck is simple and cheap, and will be found in practice much stronger and more rigid than one built up out of sectors or in a more elaborate way.

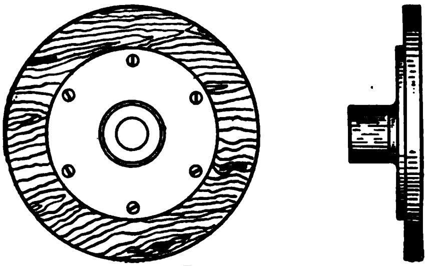


Fig. 89.

LATHE TOOLS.

Of lathe hand tools the first to be considered, as also the first to be used, is the **gouge.** It is used for reducing the stock to be turned, from a rough or rectangular shape to a cylindrical form, preparatory to smoothing and finishing. It is ground and beveled on the back or convex side, and the shape of the cutting edge should be of the same curvature as the inside, or upper side, of the tool. Gouges are made in all sizes, one of which is illustrated in Fig. 92; but for the pattern maker's use four gouges, ranging from ¼ inch to 1¼ inches, will be found sufficient for all purposes.

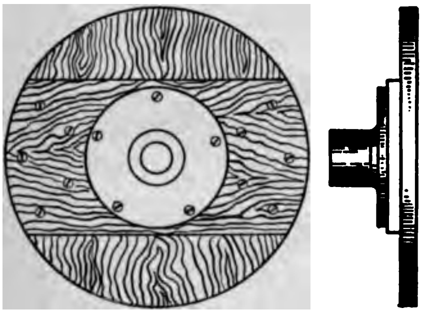
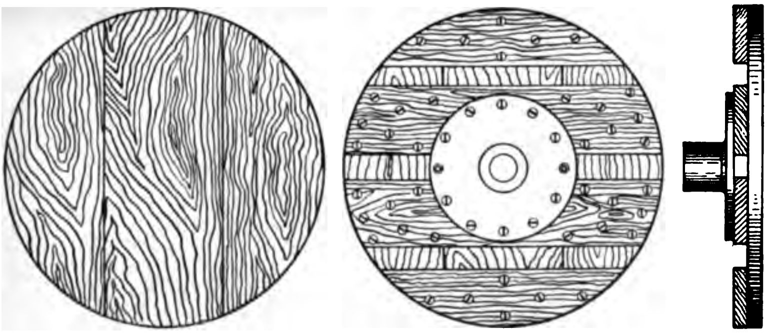


Fig. 90.

Before using the gouge, and indeed any lathe-cutting tool, the workman should take care to see that the tool rest has been elevated above the center line of the lathe centers, from ¼ inch for small work to 1 inch or more for large work. The position of the gouge, when in use, is horizontal and at about a right angle to the tool rest. It should not, however, be laid on the rest so as to use only the extreme point of the tool, but should be tilted over, first to one side and then to the other, so as to bring all parts of the cutting edge, successively, in contact with the wood that is being turned.



a Fig. 91. *b*

The gouge may be used by the beginner without hesitation, as in no position, whether tilted or on its back, will it catch or rip into the wood. The tool should be held firmly by the extreme end of the handle, in the right hand, while the left hand rests against the tool rest, the blade of the tool being grasped lightly with the fingers, and passing through and under the left hand while resting on the tool rest.

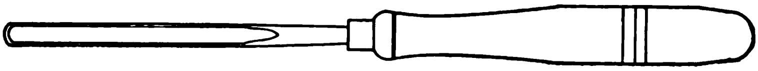


Fig. 92.

The turning gouge, being curved, can be used only as a roughing-down tool or for turning out hollows, and cannot be used for finishing. It will not make a straight, true, or smooth surface. For this purpose, in common and ornamental turning, the **skew chisel**, one size of which is shown in Fig. 93, is used. This form of chisel is made in all sizes from ⅛ inch to 2½ inches in width, but, unlike the gouge, requires considerable practice and skill for its successful use.

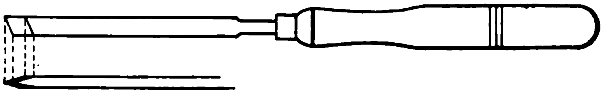


Fig. 93.

The skew chisel is held slightly tilted so that while the short edge of the blade touches the tool rest, the long edge will be slightly above the rest, so that the long corner of the skew point extends *up* and well *over* the cylinder which is being smoothed, thus preventing the long skew point from catching and tearing into the work. All the cutting must be done with the short part of the skew edge, say one-half inch only of the cutting edge, the tool resting not only on the tool rest, but resting also firmly on the cylinder that is being turned, just as a plane rests on a board while cutting and removing the shavings from its surface. The right position for this tool is hard to obtain at first, and can be acquired only by patient and continued practice. In no case, however, should the skew chisel be held *flat* on the tool rest, or used as a scraper, this not being allowable or good practice either in common or in ornamental turning. One skew chisel each of the ¼-inch, ½-inch, 1-inch, and 1½-inch sizes will be found sufficient for all ordinary work.

While the skew chisel works with great rapidity and does smooth and very satisfactory work in all kinds of ornamental turning, the dimensions obtained with this tool are not so accurate for pattern work as those obtained by the regular pattern maker's **scraping tools.** These tools, whatever may be the shape of the points or cutting edges, are all flat like the skew chisel, and are ground or beveled on one side only. Indeed there is no better wide scraping tool for large surfaces than a common firmer chisel after it has been worn short so as to be free from vibration.

Scraping tools are made in many forms and shapes, and are ground by the workman to suit the requirements of his work. A few of the many shapes in common use are illustrated in Fig. 94.

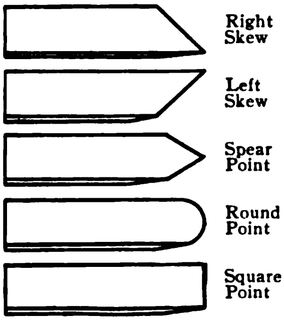


Fig. 94.

These tools should be ground with a very short bevel, and must be sharpened much oftener than a cutting tool. The revolving wood, passing at right angles to the sharp edge wears it away more quickly than it can a cutting tool, for the latter is also worn away on the slanting side of the bevel.

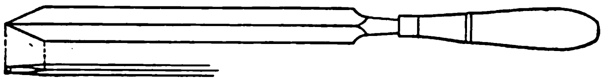


Fig. 95.

A very necessary tool for all kinds of wood turning is the **parting** or **cutting-off tool,** shown in Fig. 95. This is used as a scraping tool for cutting recesses in the work and for cutting off finished work from the face-plate, and will also be found useful for many other purposes.

SAWING MACHINES.

As a time-saving and labor-saving machine a good **circular saw bench** is necessary in every well-equipped pattern shop.

The saw bench of which two views are shown in Fig. 96, is unsurpassed in capacity and in the variety of work for which it may be used. It is provided with two saw arbors, one of them carrying a rip and the other a crosscut saw, either of which can

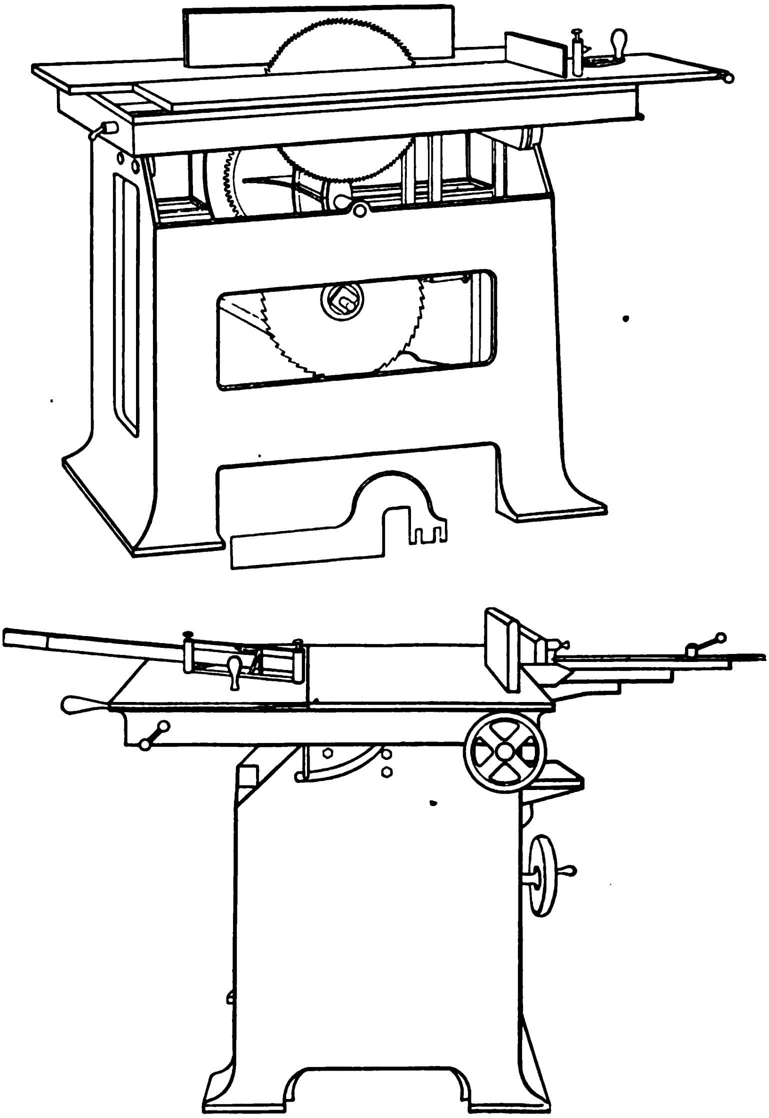


Fig. 96.

easily and quickly be raised to a cutting position. The front half of the table is made to slide, while the whole table can be tilted to an angle of 45°, and will remain in any position desired without clamping. As shown, it is provided with adjustable gages for crosscutting or mitering, and with an adjustable fence for ripping, all of which are removable at will, leaving the whole upper surface of the table clear. Fig. 97 gives a view of the table from above. As in the case of the turning lathe, the intended speed of the saw countershaft is indicated by the manufacturer.

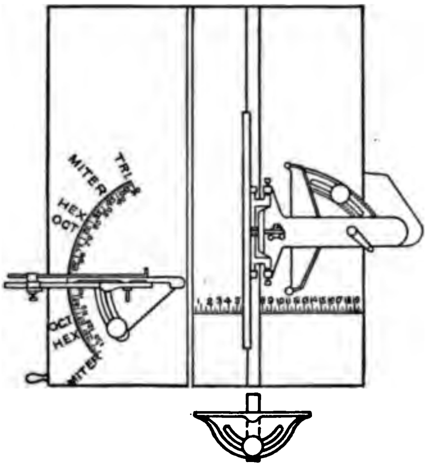


Fig. 97.

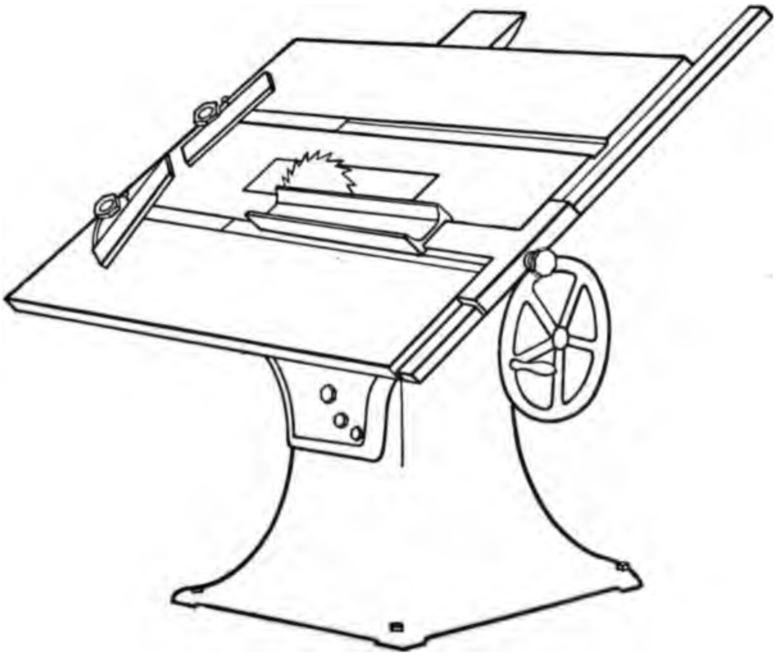
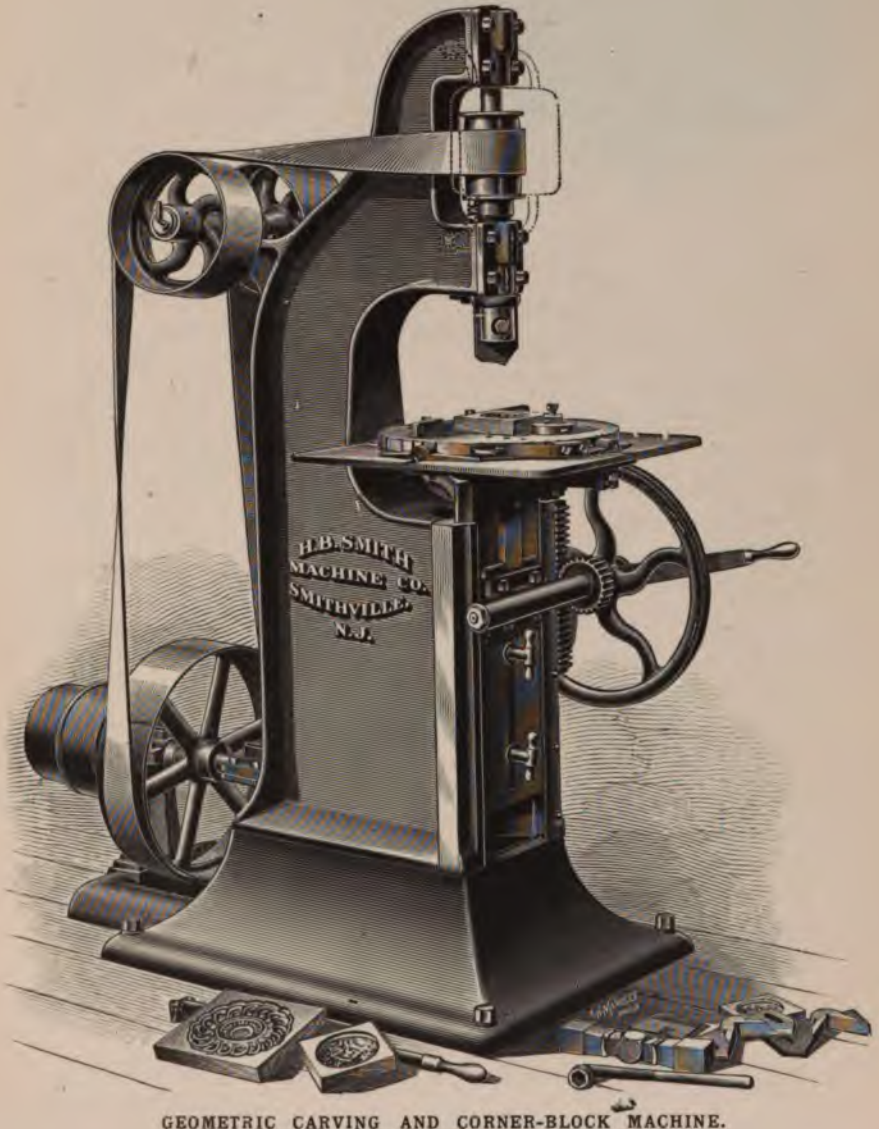


Fig. 98.



GEOMETRIC CARVING AND CORNER-BLOCK MACHINE.

H. B. Smith Machine Co.

The single-arbor circular saw bench shown in Fig. 98 is a less expensive machine than that just described; but the time lost in having continually to change the saw on the single arbor from rip to crosscut and back again for pattern work, is a very annoying as well as expensive inconvenience.

BAND AND SCROLL SAWS.

A good **band saw,** such as the one illustrated in Fig. 99, is indispensable for cutting the curves and irregular shapes that form a part of so many patterns. The best machines of this description have a tilting table which can be set and clamped at any angle, enabling the workman to give the required level or draft to his work.

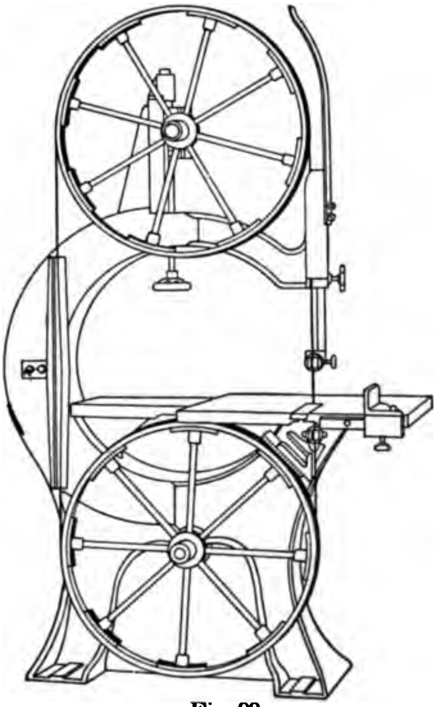


Fig. 99.

With a sharp and well kept saw, there is no more rapid or correct method of cutting out and making circular core boxes of all sizes whose length is within the capacity of the machine. The block from which the core box is to be made must be cut perfectly square on the end that is to rest on the saw table; and, if this end of the block is not large enough to give sufficient base to hold it in an upright position, the block can be supported against the blade of a try-square, or, better still, against a wooden bracket made for the purpose.

The **scroll saw,** illustrated in Fig. 100, is necessary for cutting inside curves and openings in which a band saw could not be used. Like the band saw it should have a tilting table. Where both saws cannot be afforded, the scroll saw will take the place of both.

While not working so rapidly as the continuously cutting blade of the band saw, it is, when kept sharp and in good running condition, a great time- and labor-saving machine.

PLANING MACHINES.

Because of the fact that pattern lumber can be bought already dressed to any required thickness, a planing machine is not found in every pattern shop. The ordinary surface planer, however, will not take the twist, or wind (*i* as in *find*), and the curves out of the surface of the lumber—a matter of very great importance in pattern work, and one which requires a great deal of time if the planing is done by hand.

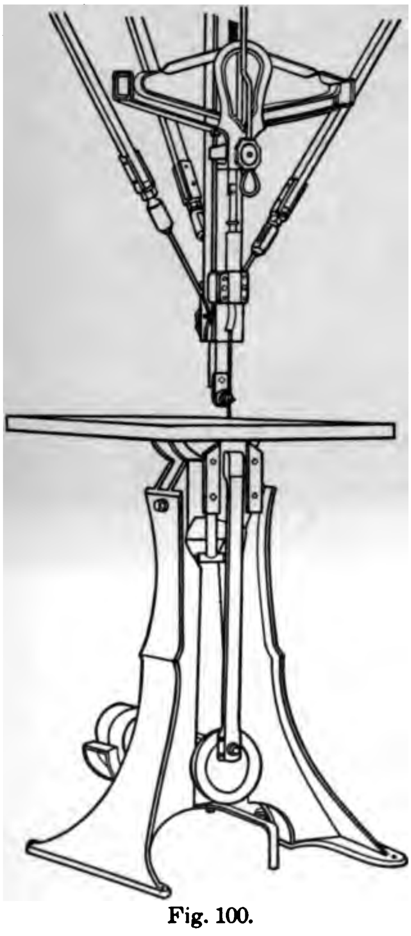
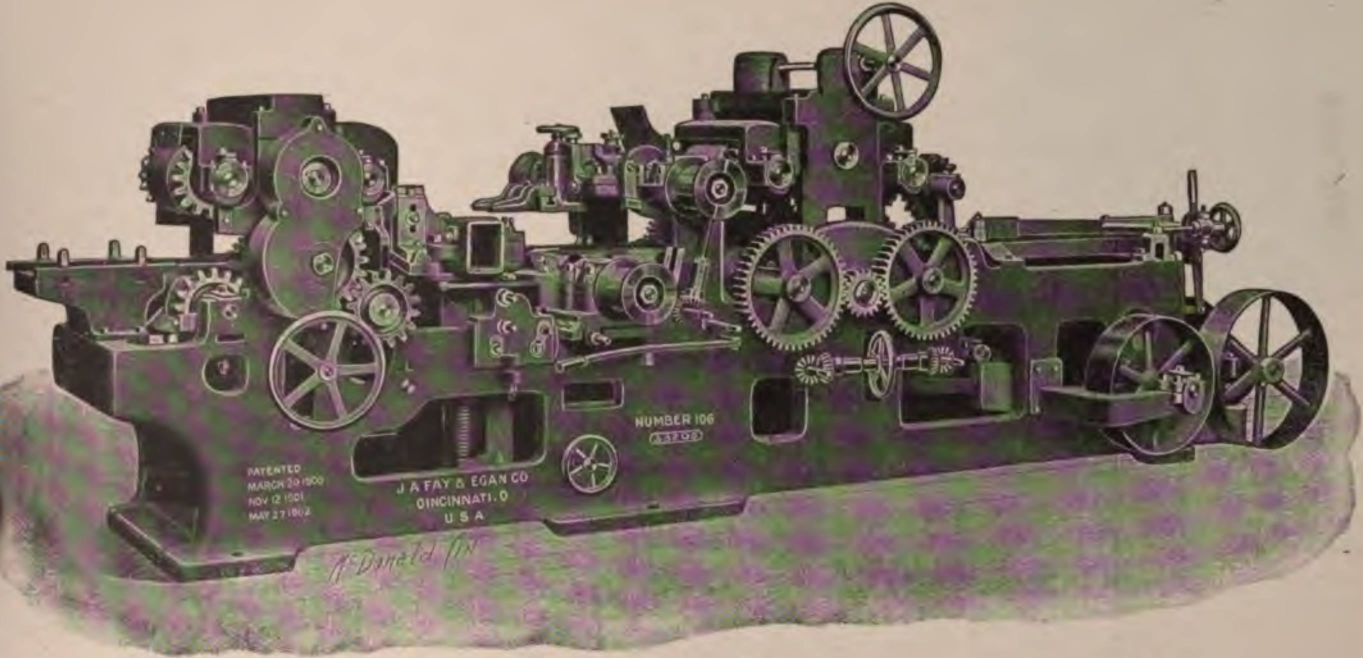


Fig. 100.

The **hand planer and jointer,** illustrated in Fig. 101, is almost indispensable, not only for facing the sides of boards perfectly true, straight, and free from wind, but also for jointing the edges, and for making perfectly-fitting glue joints in a manner superior to any hand work. These machines can be bought in widths of from twelve to thirty inches. A machine sixteen inches wide is a very desirable size for pattern work.

It will readily be seen that the running of a board over the hand planer, while facing the surface straight and true, will not reduce the piece to a uniform thickness. To avoid the necessity for much hand work in accomplishing this result, first face the piece on the hand planer so as to make one true side, and then run it through a surface planer



FLOORING MACHINE.
J. A. Fay and Egan Co.

similar to the one illustrated in Fig. 102. If they can be afforded, both of these machines (especially the hand planer) will return large profits on the money invested in them, because of the time and labor saved and the superior quality of the work done.

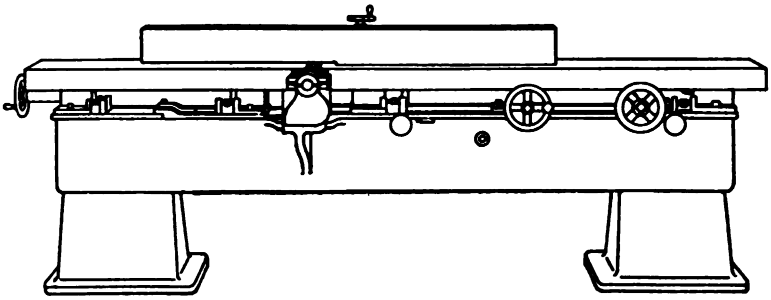


Fig. 101.

Among the many labor-saving tools of late years, there is perhaps none more popular and none more indispensable in a pattern shop than the **universal wood trimmer.** It will cut any end or angle within the capacity of the machine; and an end which would take from ten to fifteen minutes to square and true up

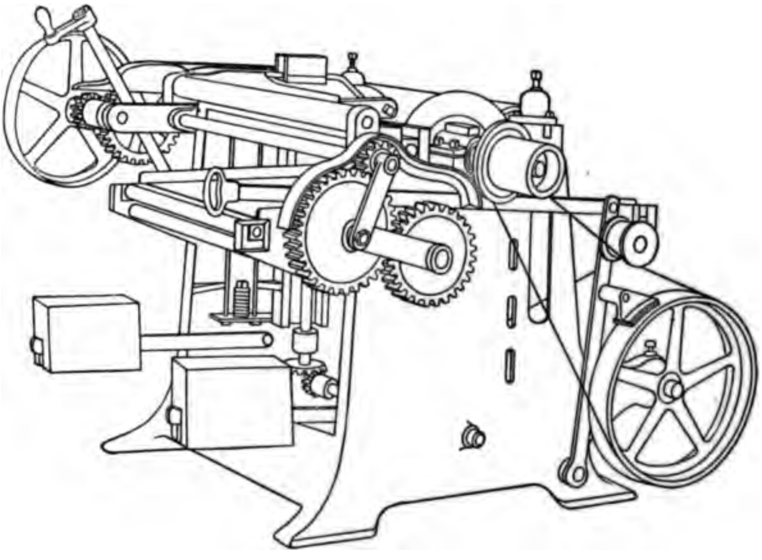


Fig. 102.

correctly by hand with square and plane or chisel, can be finished in as many seconds with this tool. It is made in many sizes, from the small bench trimmer, two views of which are shown in Fig. 103, to the large machine illustrated in Fig. 104. The former will cut 6 inches wide and 3 inches high. The larger machine will cut 20½ inches wide and to a height of 7½ inches.

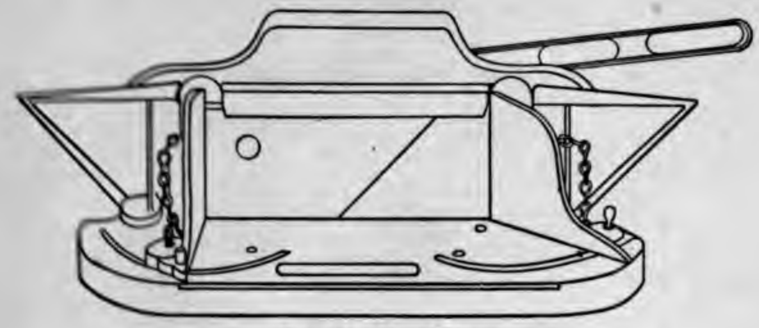


Fig. 103—Front View.

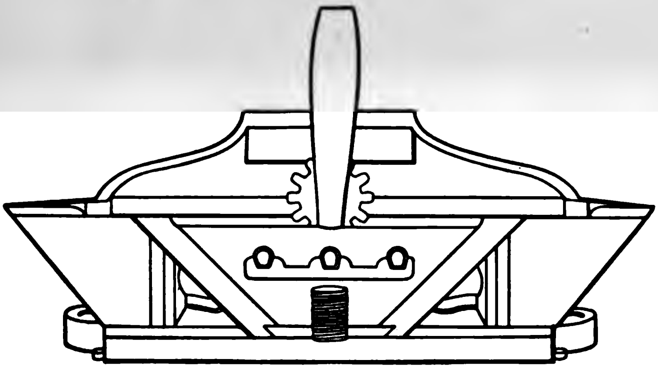


Fig. 103—Rear View.

The small No. 0 machine, shown in Fig. 103, is so comparatively inexpensive, and the time it will save so great, to say nothing of the quality of the work produced, that it should be on the bench of every pattern maker. These machines will cut the acute angles between 45° and 90°, and the obtuse angles between 90° and 135°.

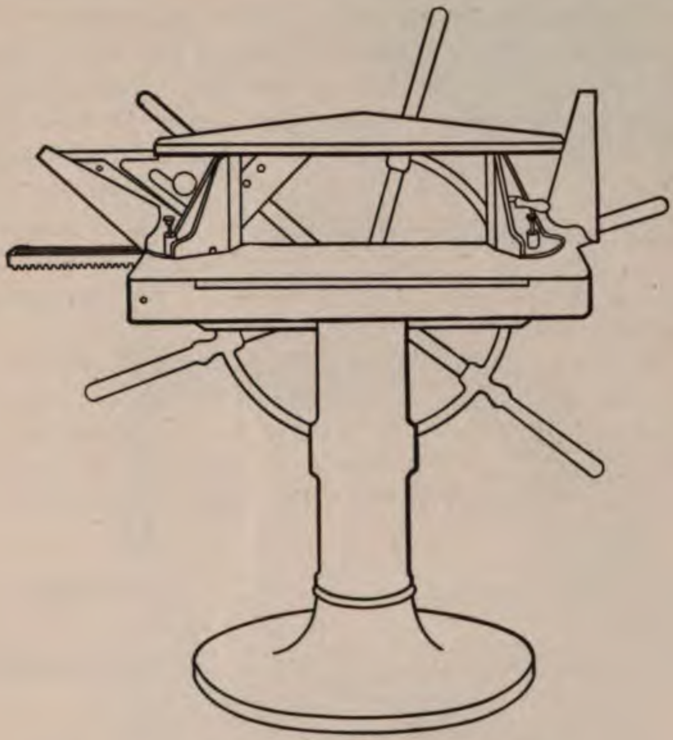


Fig. 104.

METHODS OF MOULDING.

As has already been said, it is necessary that the patternmaker should have some knowledge of moulding in order that he may construct his patterns so that they can easily be removed from the sand. A brief description of the general method employed will suffice.

Ordinarily, a casting is made in a **flask** consisting of two parts, each containing its complement of sand. The upper part is called the **cope,** and the lower part the **nowell** or **drag.** The pattern is sometimes made in two pieces that *part* along the line separating the cope and the drag. Thus in Fig. 105 the pattern separates with the flask, on the line A B; and when so separated, the cope is turned upside down and the portion of the pattern C is lifted out. The part D is lifted out of the drag in the same way.

In the case of moulding a hollow object, the internal cavity in the casting is formed by means of a dry sand **core,** which rests in impressions made in the sand by **core prints** attached to, and forming a part of, the pattern. To illustrate this, let it be required to cast the hollow cylinder shown in Fig. 106. The wooden pattern necessary to produce this hollow cylinder is shown in Fig. 107, which, as will be seen, represents the cylinder only externally by the part A.

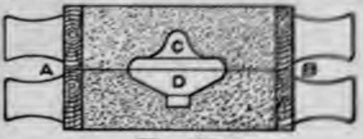


Fig. 105.

The core prints, one on each end of A, are represented by *x* and *y*. These projections form part of the pattern, and make their impressions in the sand with the part A, which alone represents the required cylinder. The **core box,** in which the dry sand core is formed, is shown in Fig. 108. The length of the inside of the box will be the extreme length of the pattern including *x* and *y*, and the inside width will be the exact diameter of the core prints. In this case, the core being a cylinder, only a half core box (Fig. 108) is used. In it are made two semi-cylindrical cores, which, after being dried, are cemented together, thus forming the complete cylindrical core required.

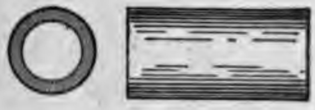


Fig. 106.

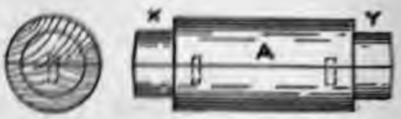


Fig. 107.

To mould this halved or *parted* pattern, as it is called, the upper half of the pattern is laid on the moulding board, and the *drag* is turned over it with the bottom side of the drag up and the parting side on the moulding board, as shown in Fig. 109. After being "rammed up," the drag and moulding board are turned over and the board removed, when the parting of the pattern will be exposed, the half pattern being imbedded in the sand.

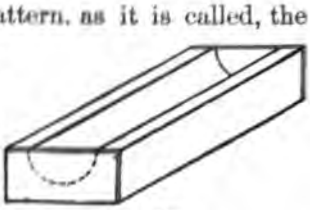
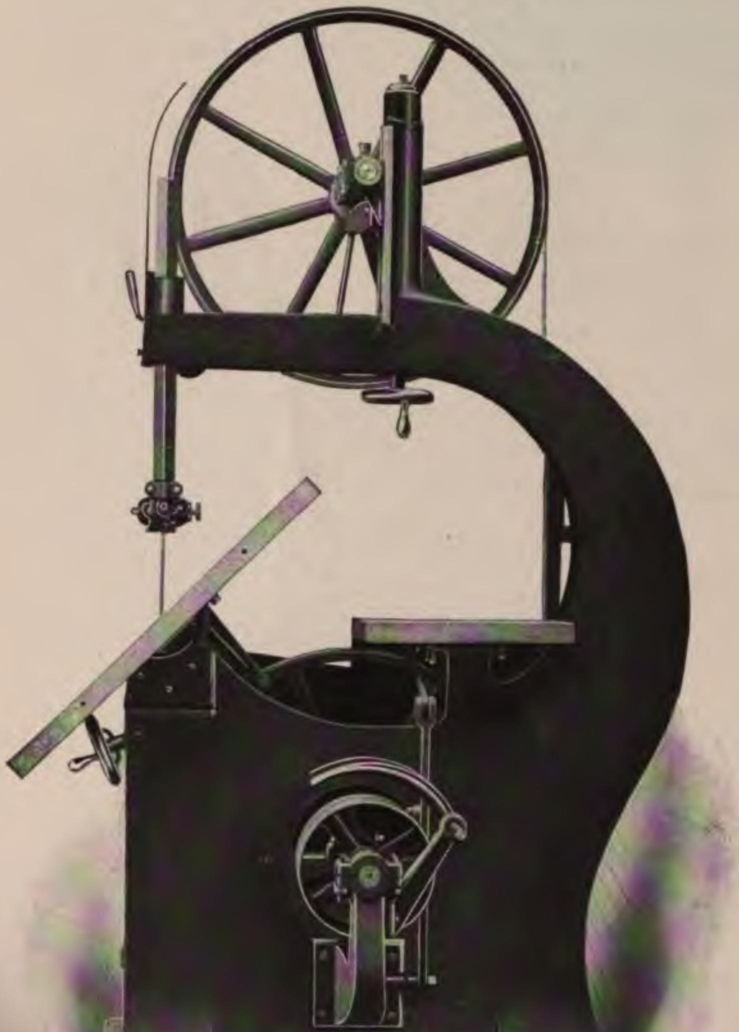


Fig. 108.



BAND SAW.

Oliver Machinery Company.

The second half of the pattern is now placed in position on the first, and dry **parting sand** is spread over the surface of the wet or "green" sand; the cope is put in position on the drag, as shown in Fig. 110, and rammed up. Upon the cope and the drag being separated, the sand will separate on the line to which the parting sand has been applied, which, as will be seen, is the line of parting of the cope and the drag, one half of the pattern remaining in each.

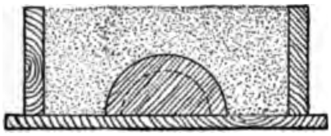


Fig. 109.

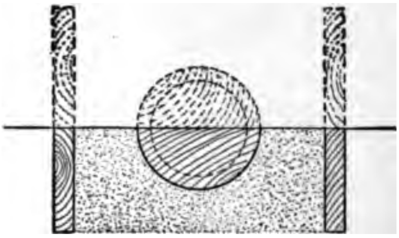


Fig. 110.

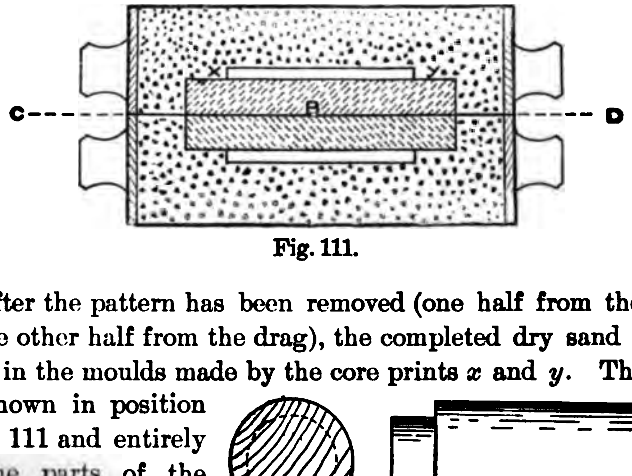


Fig. 111.

After the pattern has been removed (one half from the cope, and the other half from the drag), the completed dry sand core is placed in the moulds made by the core prints x and y. This core B is shown in position in Fig. 111 and entirely fills the parts of the mould made by x and y, leaving between itself and the surface of the mould made by A, room for the metal to be pou[illegible]h is to form the required cylinder.

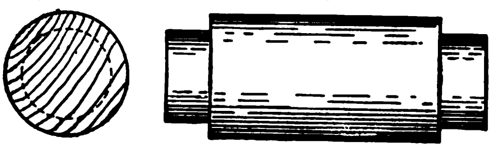


Fig. 112.

[illegible] he above cylinder it is not necessary that the [illegible] parted (made in two halves) as shown in Fig.

107. Patterns for small work, and even for large castings, are often made in one piece, as shown in Fig. 112. To mould this solid pattern it is placed on the moulding board with sufficient sand to keep it from rolling, and the drag is inverted over it as before. When the drag has been rammed up, it is turned over, and will then present the appearance shown in Fig. 113, the entire pattern being embedded in the sand. The sand is now cut away and removed, as shown in Fig. 114, down to the center line of the pattern. The cut sand is smoothed; and, after dry parting sand has been applied to the surface of the wet sand, the cope is placed in position and rammed up as usual.

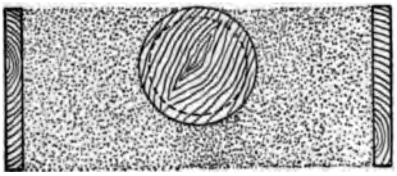


Fig. 113.

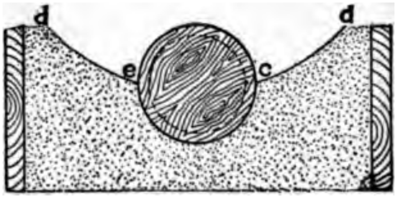


Fig. 114.

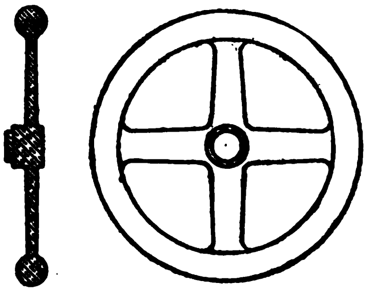


Fig. 115.

Upon the cope being removed, the sand will part along the lines *d e* and *c d*, leaving one-half of the entire pattern exposed. The pattern can now be lifted out, the core placed in position, and the cope returned to its place on the drag, when it is ready for the pouring, as in Fig. 111.

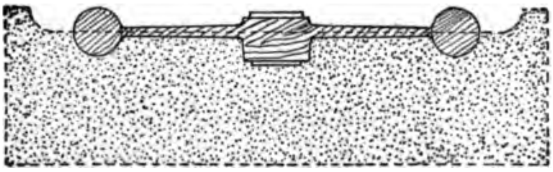


Fig. 116.

Another example of a one-piece pattern is the small brass hand wheel shown in Fig. 115. The pattern for this wheel is placed on the moulding board, and the drag inverted over it and rammed up. After the drag has been turned over, the sand is cut away and removed, not only down to the center of the rim, but also to the center line of the four arms, as shown by the dotted lines in Fig. 116.

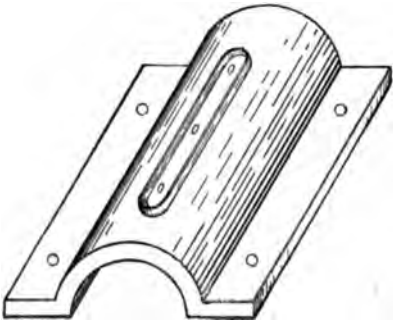


Fig. 117.

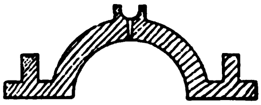


Fig. 118.

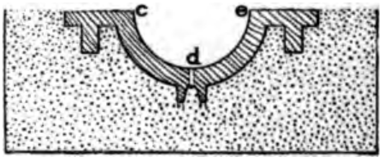


Fig. 119.

All cut surfaces of the sand are smoothed, parting sand is sprinkled over the parting thus made, and the cope is placed in position and rammed up. When the cope is lifted off, the sand will part half way down on the arms and rim, allowing the pattern to be taken out with ease.

Still another example in which a single-piece pattern can be used, is shown in the journal-box cap illustrated in Fig. 117. A cross-section of the pattern through two of the bolt-hole core prints is shown in Fig. 118. The pattern is placed on the moulding board in the inverted drag and is rammed up as usual. When the drag is turned over, the position of the pattern in the sand is as shown in cross-section in Fig. 119. The sand that may have entered the curve *c d e* is lifted out, and the necessary "draft" is given to the sand at the two ends of the opening *c d e*, as shown at *a*, Fig. 120. The cope is next placed in position, and when this has been rammed up and lifted off, the sand lying in the curve *c d e*

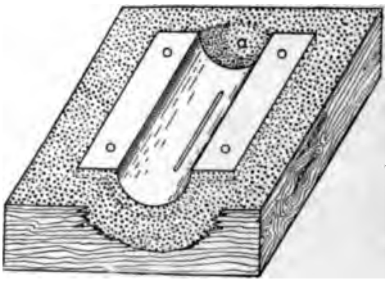


Fig. 120.

will be lifted with it. The pattern is now removed; the bolt-hole cores are placed in position; and the cope is returned to its place on the drag.

In this case the core prints should be in length at least twice the thickness of the metal through which the hole is to be cast, and the length of the cores will be equal to the thickness of the metal plus the length of the prints.

In the small sheave pully, Fig. 121, we have an example of a casting the construction of the pattern for which, so as to make it easily removable from the sand, may give some trouble to the beginner. The pattern is shown in cross-section in Fig. 122, and is moulded in a two-part flask. At first it would seem impossible to place the pattern in the sand so that either half could be removed when the cope and drag are separated on the parting line of the pattern. This is readily accomplished, however, as follows:

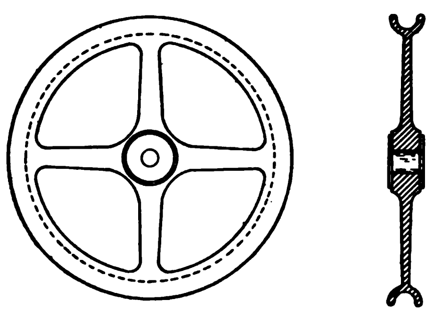


Fig. 121.

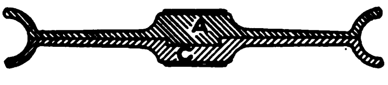


Fig. 122.

The half pattern C is placed in the inverted drag, with the parting downward on the moulding board, and is rammed up in the usual way. After the drag is turned over, the sand is cut away and removed to the center of the rim edge, as shown in Fig. 123. The cut is carefully smoothed, and parting sand applied to the cut surface. The part A of the pattern is placed in position on C, and is rammed up carefully, the sand being then cut away to the center of the rim edge of A. Parting sand is applied to the new surface, after which the cope is placed in position and rammed up.

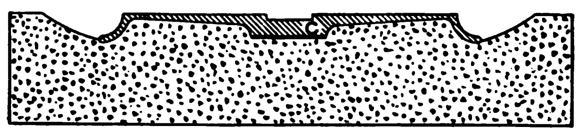


Fig. 123.

When the cope and drag have been separated, the upper half A of the pattern is taken out, and the cope is returned to its place on the drag. The whole flask is now turned over, and the drag lifted off the cope, when the ring of green sand Z, Fig. 124, will rest on the cope sand and the part C of the pattern is taken out. We thus have two partings of the sand mould, but only one parting of the flask.

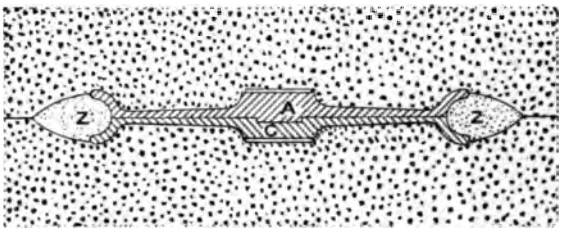


Fig. 124.

Many other examples might be given, as the case of the common two-flange pulley, which, when small, is often moulded in this way.

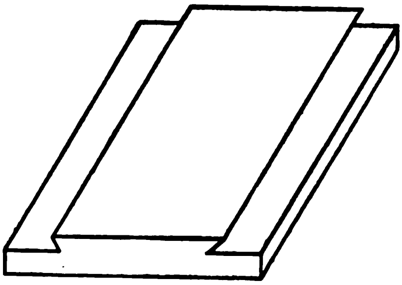


Fig. 125.

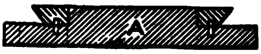


Fig. 126.

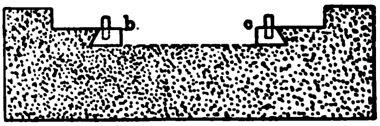


Fig. 127.

It is frequently the case that parts of the pattern will overhang so that the pattern cannot be removed from the sand in any direction, even if parted. In such cases the overhanging parts are fastened loosely to the main part of the pattern by wires or wooden pins. An example of such a casting is shown in the slide, Fig. 125. A cross-section of the pattern for this slide is shown in Fig. 126, in which the two overhanging parts are held in position by the use of pins. After being rammed up, the part A is removed, leaving the parts *b* and *c* still in their positions in the sand, as in Fig. 127. These may now be carefully moved toward the center of the opening and lifted out

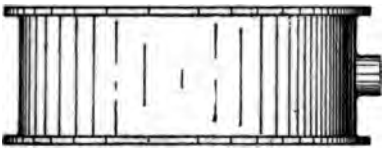


Fig. 128.

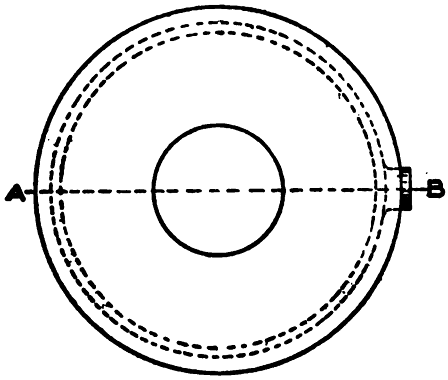


Fig. 129.

In some cases there is not sufficient room, when the main part of the pattern has been taken from the mould, to remove the projecting pieces. In such cases, the overhanging pieces or projections must be made by using dry sand cores. To illustrate this, we shall consider the pattern for the small cast-iron turbine case illustrated in Figs. 128 and 129. A section view of the casting through A B (Fig. 129) is given in Fig. 130.

The pattern is parted on the line C D and will form its own core. The boss *a*, however, will prevent the main part of the pattern from being removed from the sand, and if *a* were made loose it could not be taken out through the narrow space made by the thin side of the pattern. To overcome this difficulty a core print is fitted on the side, extending from the parting line C D to the bottom edge of the pattern, as illustrated in Figs. 131 and 132; and in the impression made by this core print a dry sand core, formed in the core box shown in Fig. 133, is placed. It will readily be seen that this core will, in connection with the pattern, form a mould which will give the casting required.

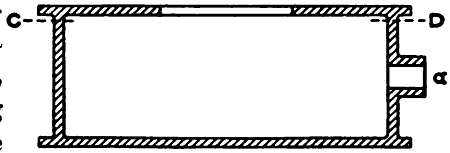


Fig. 130.

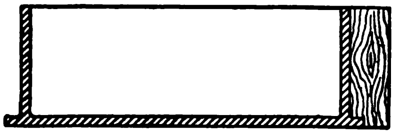


Fig. 131.

Examples in "Methods of Moulding" could be multiplied indefinitely, but the foregoing, we think, will give such suggestions as will enable the beginner in pattern making to construct all ordinary patterns so that they can easily be removed from the sand without injury to the mould.

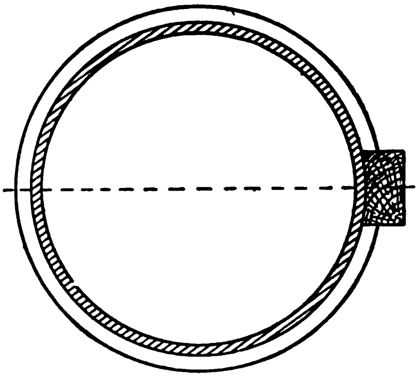


Fig. 132.

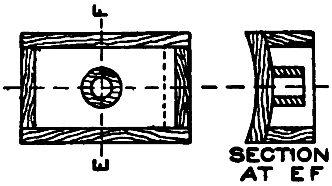


Fig. 133.

PATTERNS FROM DRAWINGS.

As already explained, the pattern maker must understand working drawings in order to construct patterns from them directly. These drawings are usually made to a scale much less than the actual size of the required work, and always represent the completed or *finished* machine or one of its parts.

Drawings are made for the machine shop to guide the machinist in cutting, turning, planing, and fitting the parts given, so as to produce in the castings the shapes, sizes, and general requirements of the articles to be constructed. Hence there is less liability for mistakes after the castings reach the machinist, as he has before him not only the drawing with its accurate dimensions to work from, but also the castings for the machine or its parts, from all of which the construction and uses of these several parts can easily be understood.

On the other hand, the pattern maker, with the aid of the same drawing, must *imagine* the casting before him, and must build something in wood which will produce that casting in metal. This pattern, in some cases, will be a duplicate of the required casting, but more often it has only a general resemblance to it, with core prints attached, and is external only, with nothing to show the internal openings, chambers, and winding passages that must be provided for by "coring." The core boxes, in which the cores are to be formed, are not shown in the drawings furnished to the pattern maker, but must be provided by him in correct shapes and sizes, in addition to the pattern itself with its added core prints.

In building a pattern the workman, as before stated, must allow for **shrinkage.** He must also allow for **draft** and for **finish.**

Shrinkage. The shrinkage of cast iron when cooling in the moulds is, as has before been stated, about $\frac{1}{8}$ inch to each foot, and the manner of obtaining the exact sizes for different parts of the pattern has been explained under the head of "Rules" (page 38). For brass or bronze castings a greater allowance must be made, averaging $\frac{3}{16}$ inch to each 12 inches. Shrinkage rules for brass ($\frac{3}{16}$ inch to the foot) can be obtained, and must be used for all patterns made from brass.

Draft. After shrinkage, the second point of importance in a well-made pattern is draft. By this term is meant the bevel or taper made on all vertical parts of the pattern so that it can easily be lifted from the sand without injury to the mould. This is best illustrated as in Fig. 134, in which it will be seen that if the diameter of a pattern at *a* were to be the same as that at *b*, the latter point would drag over the whole length of the sand until it reached the former point. As the sand is held together only very lightly, this dragging would be likely to dislodge some of the particles and make it necessary to mend the mould. In order to avoid this, the diameter at *a* is made slightly greater than at *b*, so that the body of the gland is tapering, and the moment it is started out the whole surface from *a* to *b* is clear of the sand and can be removed without injury thereto. This difference in the diameters at *a* and *b* is called the *draft* of a pattern. The amount of draft depends upon the length of the part that is to be drawn out of the sand.

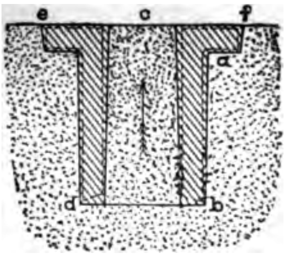


Fig. 134.

he allowance for draft varies with the pattern, and is often r or less on different parts of the same pattern. For example, ıft on the outside of the pattern of a pulley rim 24 inches in er and 6 inches face, should be $\frac{1}{8}$ inch to the foot, while on ide of the rim and on the hub of the pully it should be in the f $\frac{3}{8}$ inch to the foot. The reason for this difference is that e of the rim is often turned and finished *straight*, and for ason the least possible amount of draft that will allow of the ı being removed from the sand should be used; while on the of the rim a greater amount of draft strengthens the rim, which must sustain the strain and pressure of the belt. In general the draft should be from $\frac{1}{8}$ inch to $\frac{3}{8}$ inch for each 12 inches, the latter amount in all cases where the removal of the

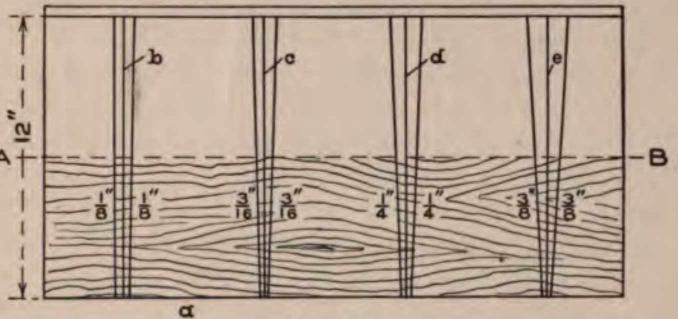


Fig. 135.

metal thus added will not greatly increase the expense of working the casting. To obtain any required amount of draft correctly, a draft template, kept with other tools and templates, will be found convenient and useful, saving much time when changing from one ratio of draft or bevel to another. It is made as follows:

Take any straight-grained board 14 inches to 16 inches long and $12\frac{1}{4}$ inches wide, as shown in Fig. 135. Having jointed the edge *a* perfectly straight, draw the line *b* perpendicular to the edge and 12 inches long, using a square and a sharp-pointed knife (not a scratch-awl or a lead pencil). On the edge *a* carefully measure $\frac{1}{4}$ inch on each side of *b;* and at the upper extremity, with the same care, measure $\frac{3}{8}$ inch on each side of *b;* connect the last two points thus found with the first two on the edge *a*, by a sharp knife line, and the result will be a right and left slanting line, having, with reference to the perpendicular, a slant of $\frac{1}{8}$ inch to a foot. These lines should each be marked "$\frac{1}{8}$ inch," as shown in the drawing.

Now draw a second perpendicular *c*, at a distance of $1\frac{1}{2}$ inches or 2 inches from the first. On the edge of the board *a*, again carefully mark off $\frac{1}{4}$ inch on each side; at the other extreme mark off $\frac{7}{16}$ inch on each side of *c*, and again connect the latter points with the former. The result will be a taper of $\frac{3}{16}$ inch to a foot. Again repeat the process, making the taper $\frac{1}{4}$ inch, and lastly $\frac{3}{8}$ inch, to a foot. Mark the pairs of right and left-hand tapers respectively $\frac{1}{8}$ inch, $\frac{3}{16}$ inch, $\frac{1}{4}$ inch, $\frac{3}{8}$ inch, as shown. These lines having been obtained permanently, the width of the board may be cut down from $12\frac{1}{4}$ inches to 6 inches (as shown by the dotted line A B), and the board then shellaced.

To use this template, place the bevel against the edge *a* of the board, and carefully adjust the blade to the $\frac{1}{8}$ inch, $\frac{3}{16}$ inch, or other draft, right or left as may be required. It will readily be seen that whatever may be the width of the surface to which the bevel is applied, the taper or draft will be in the exact proportion of the given amount for each 12 inches.

Finish. The term *finish*, in pattern making, refers to the additional amount, after shrinkage and draft, which must be added to the pattern in places where the casting is to be planed, turned, chipped and filed, or "fitted," in the machine shop. The amount that is to be so added is, to a certain extent, though not wholly, independent of the size of the piece. For small articles whose longest dimension does not exceed three or four feet, an addition of $\frac{1}{8}$ inch to the surface to be finished is usually sufficient. For larger dimensions it may be necessary to add as much as $\frac{1}{4}$ inch or $\frac{3}{8}$ inch, but very rarely more than this. In making this allowance it is also well to bear in mind the tendency of the casting to warp in cooling. Where the thickness of the metal varies to any great extent, there is a greater liability to warp than if a uniform thickness prevails throughout the whole. Hence, in such cases, a greater allowance must be made for the finishing.

On small pieces and where the moulding is carefully done it may be possible to make as small an allowance as $\frac{1}{16}$ inch, but as a general rule sufficient metal should be put upon the casting to allow the cutting tool of the finishing machine to cut well below the surface so that it shall not become dulled by the sand and hard scale on the outside.

A pattern for the plain cast-iron bar illustrated in Fig. 136 will afford a good example of the allowance necessary for finish and for draft. This bar is to be finished all over, the finished sizes being 36 inches long, 1 inch wide, and 1 inch thick.

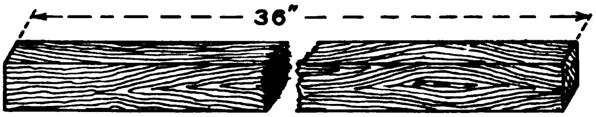


Fig. 136.

A slender bar of this length is liable to warp or bend when cooling in the mould, and for this reason the bar should have an allowance of at least ⅛ inch all over for finish, thus requiring a pattern 36¼ inches long, 1¼ inches wide, and 1¼ inches thick. Moreover, to enable the moulder to remove the pattern from the sand without injury to the mould, we must add on two of the opposite sides a draft of about ⅛ inch to the foot, making a cross-section through the pattern of the shape and dimensions as shown in Fig. 137.

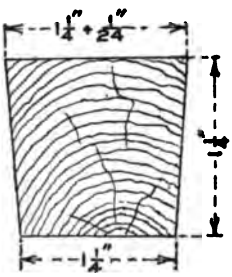


Fig. 137.

When accuracy is required in testing bars 36 inches × 1 inch × 1 inch (which are seldom finished), they are often moulded partly in the cope and partly in the drag, as shown in Fig. 138, the parting being on the line *a b*. In this position the inclination of the sides of the pattern in the mould is so great that no draft is required, the pattern being simply a square bar of wood of dimensions of 36 inches × 1 inch × 1 inch, measured with the shrinkage rule.

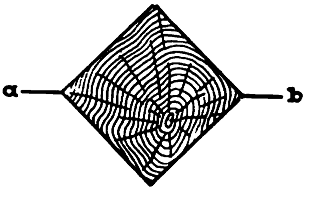
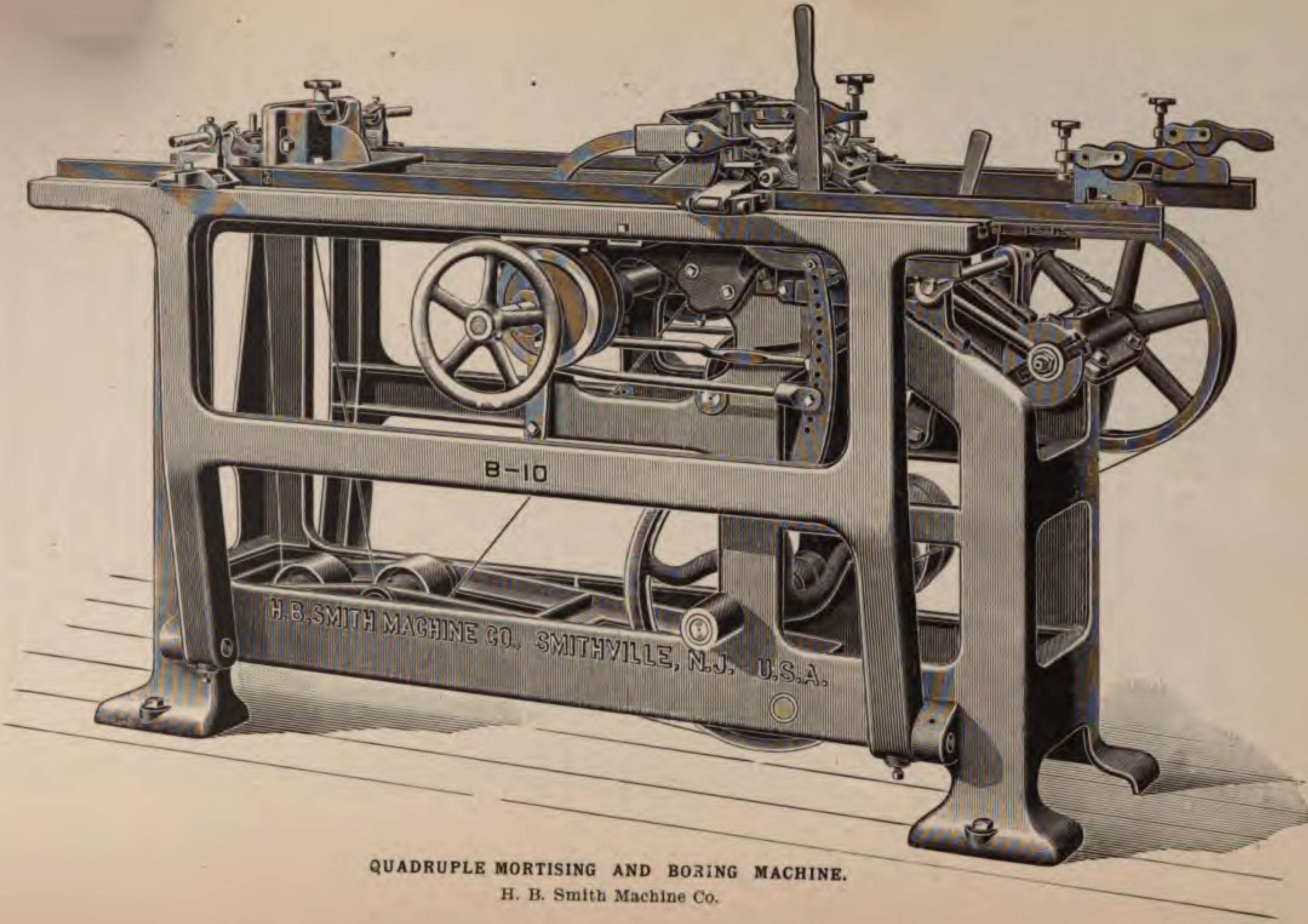


Fig. 138.


B—10
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QUADRUPLE MORTISING AND BORING MACHINE.
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PATTERN MAKING.

PART II.

SIMPLE PATTERNS.

The simplest patterns are those which are made in one piece, and which require no coring, although the castings themselves may be hollow.

The first thing which the pattern maker should decide in commencing a pattern, is the way in which it is to be removed from the sand, and where the parting line, if there is one, should be. As an example of a simple pattern of one piece made without a dry-sand core, the stuffing-box gland (shown in Fig. 134, Part I) is a good illustration. It is readily seen that if the pattern of such a gland were to be imbedded in sand, as shown, there is no reason why it could not be lifted out without disturbing any of the surrounding or the internal sand. The drawing represents the pattern with *draft* and *finish* added, the finished gland being shown by the dotted lines.

In every pattern of this kind, forming its own core, it is necessary to allow double draft on the inside, so that the pattern may be rapped and removed without injury to the green-sand core, which at best is not very stable, and which should be used only when the gland or other hollow casting is of such size as to give a large and stable core.

Except in a few special cases, it is much better to put core prints on the ends of the pattern and use a dry-sand core in place of the green-sand core illustrated above, thus avoiding the unnecessary waste of metal added by the double draft on the inside of the casting, and the expense and labor of removing it in the machine shop.

In order to give a better understanding of the methods employed in Pattern Making, the object itself will be illustrated; and when it is to be finished, the finished dimensions only will be given. If the object is not to be finished, the sizes of the completed castings will be shown. These dimensions will, in all cases, be arbitrary, and can be changed at will, if for any reason alteration is necessary. The successive steps in the construction of the pattern are given in detail so that the student may fully understand the principles involved.

The first article for consideration is the *brass bushing* flanged at one end, illustrated in Fig. 139. This bushing is to be finished *all over*, and as the casting is small, $\frac{1}{16}$ inch will be sufficient for outside finish and the same for turning out the inside. On examining it with regard to moulding, we find that if moulded on end with the flange up and on the parting line of the flask it can be readily removed from the mould.

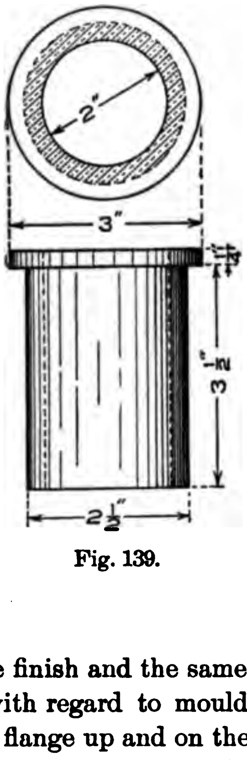


Fig. 139.

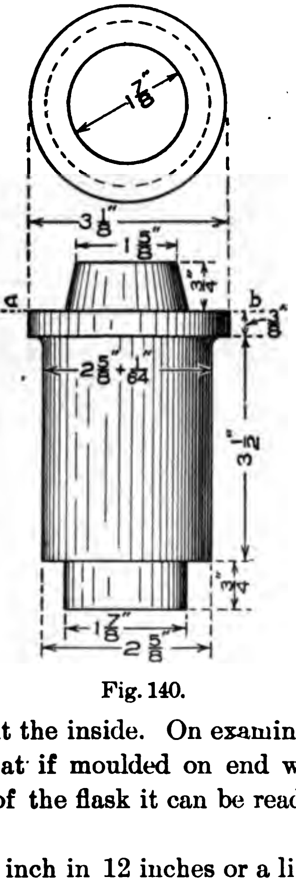


Fig. 140.

The draft in this case should be $\frac{1}{8}$ inch in 12 inches or a little less; and each core print, because the pattern is very short, need not be more than $\frac{3}{4}$ inch long. Having the finished sizes given (Fig. 139), and having decided on the amount of draft and finish, the pattern will be as represented by Fig. 140, and in the case of this simple pattern, as in all others, a full size drawing, or sketch, giving all the dimensions of the pattern, should be made by the pattern maker before beginning work on the pattern. This is good practice, and if carried out many mistakes and much loss of time will be avoided.

The lower core print should have the same proportion of draft as the body of the pattern, but the upper core print is given the excessive draft of $\frac{1}{8}$ inch to its length so that the cope can be easily lifted off and returned again over the tapering end of the dry-sand core without injury to the mould; the parting of drag and cope being on the line *a b*. This pattern may be turned from a solid block of wood, but if durability is desired the block should be glued up from 4 pieces of $\frac{7}{8}$-inch pine, care being taken to reverse the annular rings or yearly growth of the wood, as shown in Fig. 141.

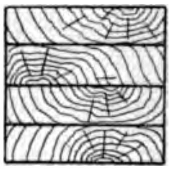


Fig. 141.

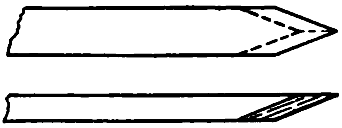


Fig. 142.

Place the block in the lathe and with the gouge turn to a cylindrical form of slightly greater diameter than the largest diameter of the pattern, say $3\frac{3}{16}$ inch. All finishing should be done by the use of scraping tools. For the body of the pattern, a firmer chisel 1 inch wide is a good tool, but the cutting edge must be ground and sharpened slightly rounding, as described for plane irons; otherwise the corners of the tool are liable to catch and form grooves on the surface.

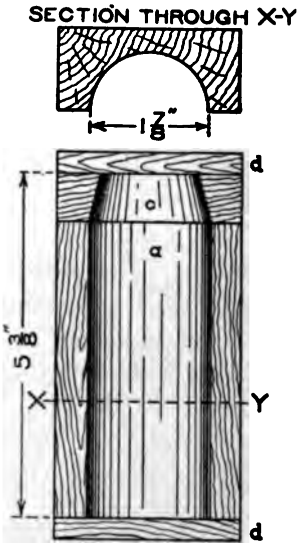


Fig. 143.

For smoothing and finishing the ends of the pattern and flange, a diamond-pointed scraping tool, Fig. 142, is preferred to all others. The core box for this pattern is shown in Fig. 143, which is representative of the half box used for all symmetrical cores. In this box, two semicircular or half cores are made, which, after being dried, are pasted together, forming the cylindrical core required. For the part *a* of the core box, a block of slightly greater length ($\frac{1}{2}$ inch or 1 inch) is first planed up to the exact size. A center line *b*, Fig. 144, is drawn with the marking gauge parallel to one of the edges, and also extends across each end of the block. From this center line, at a distance of $\frac{15}{16}$ inch on each side, the lines *d* and *e* are also drawn. Then with a second block, or strip of wood placed against the face of the block and flush with the end, the two pieces are clamped together in the bench vise, as shown in Fig. 145. Now with the dividers adjusted to $\frac{15}{16}$ inch, describe on each end of the block the semicircle which will connect the lines *d* and *e* on the ends of the block. This wood may be removed rapidly with a gouge and mallet, smoothed with a round plane of proper size and curve, and finished by sand paper rolled on a cylindrical block having a diameter $\frac{3}{16}$ inch less than the width of the required box.

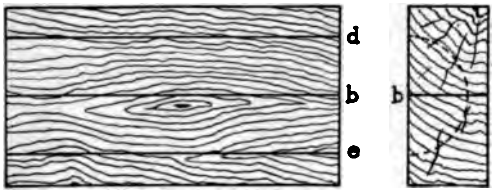


Fig. 144.

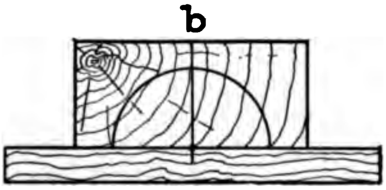


Fig. 145.

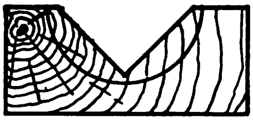


Fig. 146.

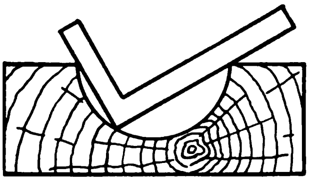
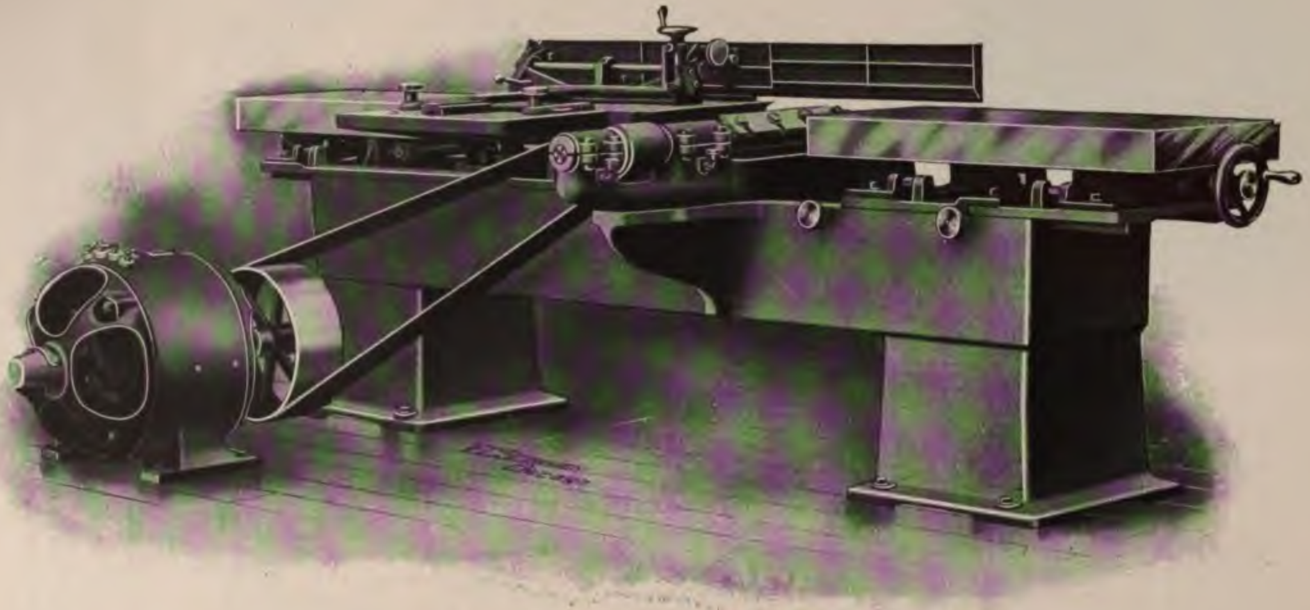


Fig. 146*a*.

Another method frequently used for small boxes, is to work out the center of the curve with a rabbet plane, forming a right-angled opening, as shown in Fig. 146, the remaining wood being removed with the round plane and finished with the cylinder and sand paper as before.



HAND PLANER AND JOINTER.

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As the work progresses, the accuracy of the curve is tested by means of a try square, or other 90° angle, as shown in Fig. 146a.

The tapered end of the box *c* (Fig. 143) is turned from a block of wood, screwed to the face plate of the lathe as shown in Fig. 147. After the hole is turned to the required depth, ¾ inch, and to the required size, 1⅞ inches on the outside, and 1⅝ inches at the bottom, it is removed from the face plate and the piece *c* is cut out, as shown by the dotted lines in Fig. 147. This piece *c* is glued and nailed to the end of *a*. The two ends of the box are now given a slight draft, (¼ inch in 12 inches) to allow the half core to leave the box easily. The end strips *d* and *d* (Fig. 143) are then nailed on and the box is complete.

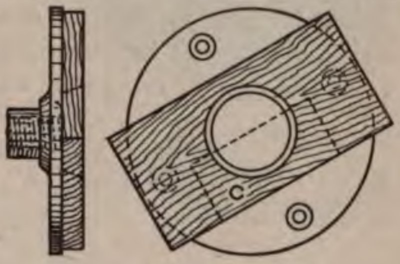


Fig. 147.

FINISHING PATTERNS.

Having completed the pattern and its core box, the surface of the wood must be covered with some material which will render it hard, smooth, and impervious to the moisture in the sand, and at the same time make it easier to be withdrawn from the mould. Pure grain-alcohol shellac-varnish is the best for this purpose. All cheap substitutes, such as wood-alcohol shellac, or copal varnishes should be avoided. They become flaky and scale off, and do not stand the exposure and moisture. Pattern makers generally make their own shellac varnish, buying only the best quality of shellac gum, and using 95 per cent proof alcohol. The proportions are three pounds of gum to one gallon of alcohol. The gum is put in a wide-mouthed bottle, or earthen jar, and the alcohol poured over it, and if well stirred three or four times during the day will (if the alcohol is of the best,) give a smooth, clear, orange-colored varnish ready for use.

A good grade of "white grain-alcohol shellac" may be made from bleached gum, or can be bought from the dealers, but it dries more slowly and does not produce so hard a surface as the orange shellac.

As the alcohol in shellac-varnish evaporates very rapidly, the brush should be kept in a vessel which is closed and air tight. A short bottle having a mouth wide enough to admit the brush is best for this purpose. A one-inch, flat, double-thickness, fitch-hair brush is good for general work. Do not use a cork, but turn a wooden cap for the bottle, such as is shown in Fig. 148. The shoulder at *a* may be $\frac{3}{16}$ inch to $\frac{1}{4}$ inch long, but must be at least $\frac{1}{4}$ inch less in diameter than the inside of the mouth of the bottle. Otherwise the shellac will cement it to the glass so that it cannot be removed. Its only object is to keep the cap nearly central on the bottle. The handle of the brush must be tightly fitted into a hole through the center of the cap and fastened with a screw or brad; allowing the brush to reach within one-half inch of the bottom of the bottle. Keep the bottle one-third to one-half full of shellac and use the brush with the cap on the handle. The shellac will make a tight joint between the bottle and the cap, and if the proper amount of shellac is kept in the bottle, the brush will always remain soft.

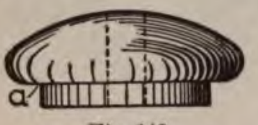


Fig. 148.

For small patterns, such as the bushing described, the small quantity of shellac needed can be used directly from the bottle. For large work however, an earthern-ware cup or mug should be used, but the shellac left over should always be returned to the vessel in which it is kept.

Shellac varnish should never be kept in a metallic can or cup, as the oxidation of the metal will discolor the varnish.

Having given a perfectly smooth surface to the pattern and core box by the use of very fine sand-paper, (No. 0) apply the first coat of shellac. This first coat will raise the grain and roughen the surface of the wood, which, after the shellac is perfectly dry, must be sand-papered a second time until smooth. Now apply a second coat. Should there still be roughness, a second sand-papering will be necessary. At least three coats of shellac should be used. If there is much end wood exposed on any of the surfaces of the pattern, a fourth coat may be necessary on these parts.

As regards the color in which patterns are finished there are different rules in different shops. The general rule, however, is to leave all patterns for brass or bronze, in the natural color of the wood, and shellac the core prints red. If the pattern is intended for moulding cast iron, the body of the pattern is made black and the core prints red. The parts of the core box in which the core is to be formed are also colored red and the outside of the core box black. The black color is produced by mixing lamp black with the shellac varnish, and the red color by mixing vermillion (Chinese is the best) with the shellac. The vermillion is heavy and will settle, hence it must be stirred or well shaken before using. The best method is to first use two coats of the natural colored shellac (orange or white) on all surfaces of the pattern, core prints and core box, then apply the black or red for the last coat only.

As the pattern already described is for a brass bushing, the body should be left the natural color of the pine, and the core prints on the pattern and the inside of the core box colored red.

The outside of the core box may be left the natural color or made black, as preferred. The outside of the core box, having no part in the formation of the core, is not necessarily so well and smoothly finished as the inside.

All nail holes or any defects in the wood should be filled with beeswax applied with the warm blade of a knife, or narrow chisel, warmed by holding in hot water. The beeswax should always be used after the first coat of shellac has been applied, as it will then hold better. The sand-papering of the pattern, after the first coat. will smooth the wax and bring it even with the surface of the wood. The time required for a coat of shellac to dry is from eight to twelve hours, depending upon how heavily it may have been applied, even though to the touch the surface may seem dry in one or two hours.

If a hard, *durable* surface is required on the pattern, twelve, or better, twenty-four hours must be given between each coat. The roughness will then sand-paper off as a dry powder without gumming the sand-paper, and leave a hard, smooth surface for the succeeding coat of shellac.

The second casting to which attention is called, is the ***brass bearing*** represented in Fig. 149, which is to be finished all over. On examining the drawing, first with regard to removing the pattern from the sand, we find that it must be moulded on its side, and that the moulder may not lose time in cutting away the sand (see Figs. 113 and 114, Part I) the pattern must be *parted*, or made in two halves.

For finish on this small pattern $\frac{1}{16}$ inch will be sufficient, and draft will be required only on the ends of the pattern, and on the ends of the core prints, which in this case, should be not less than 1 inch long. This is necessary, because the core-print moulds must sustain the weight of the dry-sand core.

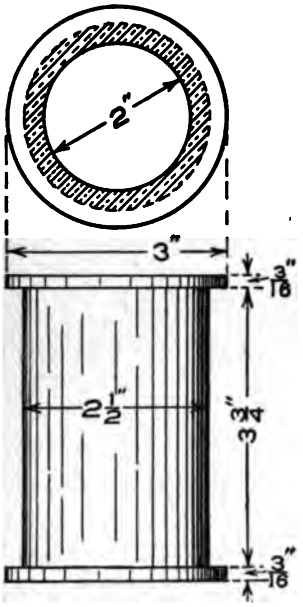


Fig. 149.

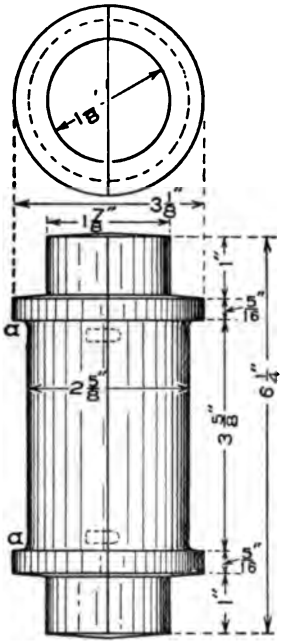


Fig. 150.

The pattern for this casting is represented by Fig. 150, in which it is seen that, unlike Fig. 140, the body and core prints are perfectly straight, a slight draft $\frac{3}{16}$ inch to 12 inches being given to the ends of the pattern and to the ends of the core prints only. A slight curve of $\frac{1}{16}$ inch radius should also be made at the intersection of the body of the pattern, and the inside of the flange at *a*, *a*.

The wood in being prepared for this pattern should be cut 2½ inches longer than the finished pattern. The dimensions of the two halves would each be 1¾ × 3⅜ × 8¾ inches. Having fitted the two insides accurately together and dressed one edge of each straight and at right angles to its face side, with the marking gauge, draw a center line on each, not only on the face but also across each of the two ends, Fig. 151. Across the center of each piece draw, with a sharp-pointed knife and try square, a second line at right angles to the first and at equal distances from each end of the block. With dividers adjusted to 1⅞ inches, place one leg at the intersection of the two lines, and on the gauge line mark two dots, each 1⅞ inches from the center line. These dots are the centers for the dowels which are to connect the two halves of the pattern after it is finished. Bore the holes in each piece ½ inch deep with a 5/16 inch auger bit, and cut the dowel pins only ¾ inch long, gluing them into the holes of one piece and giving a projection of ¼ inch to fit in the holes of the second half of the pattern. Although the dowels are glued into the first half they must fit easily, but not loosely, in the second, and should be rounded on the ends or made cone shaped, as in Fig. 152.

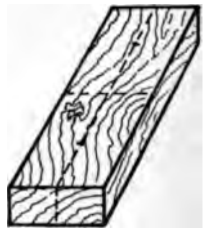


Fig. 151.

Having fitted and prepared the two blocks with their dowel pins, carefully glue them together using only a narrow strip of glue ½ inch wide on each end of the block and clamping the two together with a hand screw on each end. When the pressure of the hand screw is applied, the glue will spread inward to ¾ inch or 1 inch. Great care must be taken not to use too great a quantity of glue, or it will spread in far enough to bind the two halves of the pattern together so that they cannot be separated when turned and finished. The blocks should remain in the hand screws, after

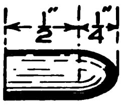


Fig. 152.

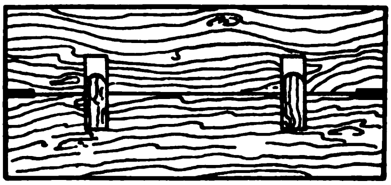


Fig. 153.

being glued, from four to six hours, depending on the temperature of the room in which the gluing is done. Our pattern block is now ready for the lathe and will be as represented in Fig. 153, which is a longitudinal section through the dowel pins.

When centering for the lathe centers, great care must be taken to mark the centers exactly at the intersection of the center-gauge lines on the ends of the blocks and the glued joint of the two pieces. The hard glue will force the lathe center to one side of the connecting joint unless a center dot or hole is first made with an awl in the exact position required. As in the case of the pattern in Fig. 140, the block is roughly turned to dimensions, all of which are a little larger than the finished pattern, by using the ordinary turners' gouges, but the final turning and finishing to exact sizes must in all cases be made with scraping tools, as described for the pattern of the *brass bushing*.

When marking off the pattern on the rounded cylinder in the lathe, care must be taken to locate the pattern in the exact center of the block, so that the dowel pins may be equally distant from each end and from the center of the pattern. Fig. 154 shows the pattern as ready to be taken from the lathe. The core print ends should be cut down to $\frac{3}{4}$ inch at each end, and finally cut off with a saw, and the ends finished with file and sand paper after removing from the lathe, when, as will be seen, the glued end having been cut off, the two halves of the pattern will separate clean and free from glue, and the dowel pins will always bring them into accurate alignment when used by the moulder in the foundry. Before removing the turned pattern from the lathe, it should be smoothed and finished with sand paper, but care must be taken not to allow the sand paper to come in contact with the sharp corners and angles of the pattern, or they will be rounded off and the work ruined. For pine, only the finest paper, No. $\frac{1}{2}$ and No. 0 should be used on lathe work, and the paper must not be held in one position on the revolving work but must be kept moving laterally, that is, from side to side, to avoid cutting depressions in the surface.

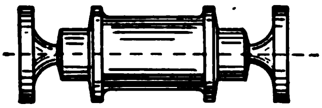


Fig. 154.

When the scraping tools are kept sharp so that they will cut freely and without pressure, a light touch of sand paper only will be required.

In the construction of this pattern, it may be made of two blocks of $1\frac{3}{4}$-inch stock as described; but the tendency of the two halves will be to become rounding on the parting line as shown by the dotted lines *c d* and *e f*, Fig. 155. This is caused by the removal of considerable wood in the process of turning, at the angles *a a a a* thus exposing fresh surfaces which are farther removed from the original surfaces of the plank, than the surfaces on the line of parting. The exposure of these deep, inside fibers of the wood will cause a shrinkage of the pores and draw the pattern more or less, according to the position of the annular growths, and also to the more or less thorough seasoning of the wood, in the direction indicated. If the pattern is intended for temporary use only, it may be constructed as above, but if durability and permanence of shape are required, the two blocks should each be glued up out of thinner stock with the annular growths carefully reversed, as shown in Fig. 156. This is done not only because thin plank is more evenly and better seasoned, but because in gluing, the tendency of the pieces to warp or spring is counteracted each by the other, and in addition the gluing of several thin pieces together

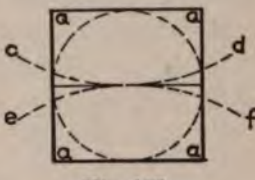


Fig. 155.

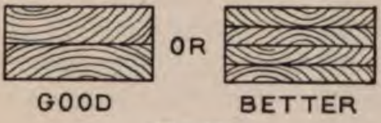


Fig. 156.

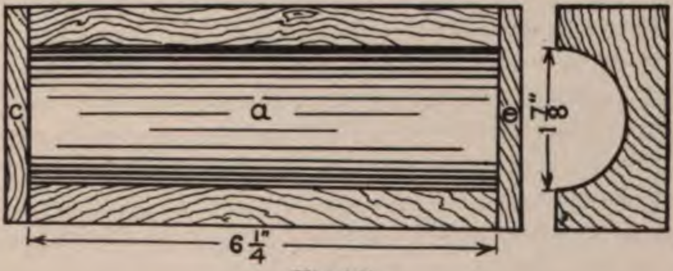


Fig. 157.

stiffens and makes the resulting piece much firmer and stronger than a large block or piece of the same size obtained without gluing.

The core for this pattern, being straight from end to end, and cylindrical, only a half core box is required, as shown in Fig. 157. After being laid off and worked out in the same manner as described for the core box, Figs. 143 and 144, cut the ends of *a* with draft of ¼ inch in 12 inches, and glue and nail on the ends *c* and *e*, which may be ⅜ inch to ½ inch in thickness.

Shellac and finish as described for pattern, Fig. 140, giving first two coats of orange or white shellac, and for the last coat on core prints of the pattern and the inside of the core box *a* use the red, the body of the pattern being left natural color (with three coats) and the outside of the core box either natural or black.

GLUING.

As the use of glue enters largely into the construction of all patterns, some instruction as to its selection and the manner of using will be necessary. When building up patterns, the connections should in all cases be made by gluing. Nails should never be used except when they can be so placed as to be entirely removed from all danger of contact with the tools used in turning and shaping the pattern, and when so employed should be used in conjunction with glue. The only advantage in their use is the hastening of the work, because they take the place of hand screws or clamps while the glue is drying.

The use of nails, however, is always unsatisfactory, for when the point is passing through the upper piece, small thin slivers are broken from the under surface, which have a tendency to separate the two surfaces instead of exerting the required pressure as when hand screws are used.

For pattern work select only the very best quality of cabinetmakers' glue, or better still, the best quality of white glue. This white glue can always be had in two forms, first, white glue, *clear*, and second, white glue *opaque*. The first is the glue without the addition of any foreign substance. The second looks much whiter than the first, because of the addition of whiting, or other mineral, to the glue. This addition does not in any way lessen the adhesive qualities of the glue; on the other hand, it sets more readily and dries more quickly, but for this very reason, it is harder to use on large surfaces, as the first brushing on one part of the work will begin to set before the entire surface can be covered. For all small or moderate-sized work, however, the opaque, white glue is to be preferred.

Good glue will keep in a dry room of any temperature for an indefinite length of time, but when cooked in the glue-pot it deteriorates very rapidly. Each successive reheating and boiling lessens its adhesive qualities, hence it should always be used *fresh* or nearly so. A greater quantity of glue than is likely to be used in two or three days should not be cooked at one time.

The cooking and preparing must be done in the regular glue-pot, made for the purpose, and sold in all hardware stores. No rule can be given for the relative quantities of glue and water to be used. Some glues, especially the cheaper grades, require much less water than the better and finer qualities. As a general rule however, pack the glue firmly in the pot and add sufficient cold water to cover it. Fill the outside kettle with cold water and boil until thoroughly cooked, so that it will run smooth and clear from the brush or paddle. It should run freely without returning and gathering in bunches or clots at the end of the paddle, but must not be so thin as to be weak and watery.

If the glue is too thick, no amount of pressure will bring the two glued surfaces in close contact, and if too thin there is danger that the joint will not hold. Always use cold water for cooking and dissolving fresh glue. Hot or boiling water will make the glue *stringy* and will require a much longer time to cook to an even and smooth consistency. Great care should also be taken to keep the outside kettle, which surrounds the glue-pot proper, full of water. If allowed to *boil dry* the glue in the inner pot will be scorched, or burned, and will then be entirely useless. It must then be thrown out, the pot washed or boiled out clean, and fresh glue again cooked. The hot water in the outside kettle should in all cases be used for thinning the glue to the required consistency. Cold water chills the glue and necessitates reheating. In cold weather the precaution must be taken, unless the room is warm and entirely free from drafts, to heat the pieces of wood before applying the glue, else the latter may be chilled and fail to set. The time required for well-made joints to dry so that the hand-screws can be removed is from four to six hours.

Sometimes a difficulty will arise in the case of large surfaces on thin material. When the glue is applied it moistens and expands the surface upon which it is placed, causing the edges to curl up and pull away from the adjoining piece which has a tendency to move in the opposite direction. In such cases *never* moisten the back of the thin pieces with water from the outside kettle, as is sometimes directed, but work quickly, spreading the glue rapidly and then place between two thick, stiff pieces of board, previously dressed true, prepared and heated for the purpose. Use as many hand-screws as can be conveniently placed on the work, and allow it to remain in these clamps until all moisture from the glue is absorbed by the two outside, heated boards. Twenty-four, or better forty-eight, hours should be given to this process if possible.

All such gluing of thin pieces should in every case be done first and allowed to dry while the other parts of the pattern are being constructed. Under no circumstances use water on any surface of seasoned wood. The reseasoning or drying out of such water will invariably distort, curl, and warp the pieces so treated after being glued together. Even the water contained in the glue is objectionable, while unavoidable, and can be most satisfactorily removed only as directed above.

In all cases where end wood is to be glued, or where the grain of the wood runs diagonally to the plane of the joint so as to present the open end wood pores for the glue, this end wood, or partially end wood joints, should be first "*sized*" with thin glue, (glue about half the thickness of that used for gluing,) and allowed to dry. This will raise the grain and roughen the surface of the joint, which, when dry, must be lightly and carefully scraped off with a sharp chisel, when it will be found that the open pores of the wood are filled with dried glue. The joint may now be glued, and the glue will hold as in ordinary jointing.

HAND SCREWS.

The hand screws, illustrated in Fig. 81, enter so largely into all gluing for pattern work, that some description of their construction and the manner of using is necessary here. The four parts of each hand screw consist of two *jaws* and two *spindles*. When using, the *jaws* must in every case be kept parallel. This is done by the adjustment of the middle or central spindle. The clamping is in all cases done by the outside or end spindle, the middle or adjusting spindle serving as a fulcrum for the jaws; the leverage and pressure being obtained by the end spindle. When clamping broad surfaces, care must be taken to see that the pressure of the jaws on the work being glued is the same at the points and at the back part of the applied portion of the jaws.

This can be easily changed at will, by slightly loosening or tightening the middle spindle, which, as before stated, is the adjusting spindle and fulcrum, and not used for clamping. After adjusting the jaws parallel and to even pressure on all their length as applied to the work, screw up and tighten the end spindle to the utmost pressure which the jaws will bear, and again examine the clamp and the work to see if the jaws are parallel and the pressure even.

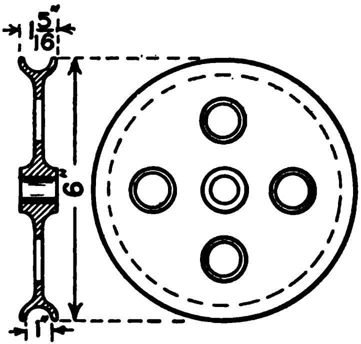


Fig. 158.

If not, loosen the end spindle and readjust the middle spindle by opening or closing as the case may require. To open and close the hand-screws for larger or smaller work, *do not* screw or unscrew *one* spindle at a time. Instead, grip the handle of the *middle* spindle in the left hand, and the handle·of the end spindle in the right hand. Hold the hand screw at arms length and whirl it from or toward you as may be needed for closing or opening the jaws In this way the spindles will each be kept in its proper relative position, and the jaws will, at all distances, remain parallel.

BUILT UP PATTERNS.

A good example of the manner in which patterns are built and glued up is shown in the construction of the pattern for the 6-inch sheave pulley shown in Fig. 158.

The groove is a semicircle 1 inch wide, and the rim containing the groove is connected with the hub by a solid web $\frac{1}{4}$ inch in thickness, and having four or six holes, each 1 inch in diameter, this web taking the place of arms. If there is to be no *finish* on the sheave, as is usual, the only allowance to be made on the pattern, *which must be parted*, will be for shrinkage and for draft.

A cross-section through the finished pattern for this casting is shown in Fig. 159.

In all large patterns of this kind, the web is first glued up in sectors, six, eight or more in number, according to the size of the sheave (see Fig. 160). The sectors are fitted by hand or on the trimmer, the ends are glue-sized, and when the sizing is dry the joints are carefully scraped smooth, and the whole glued together. After drying for four or five hours, it is sawed to a circle of $\frac{1}{2}$-inch greater diameter than the finished pattern, and the block for the hub is glued over the center. Six segments to form the outer rim are glued around on the outer edge, care being taken to *break joints* as shown in Fig. 161. If the groove is to be large, the six segments should be of half the thickness only, and a second set of segments of like thickness glued over the first, *breaking joints* not only with the first set, but also with sectors of the web.

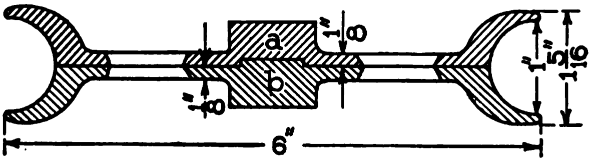


Fig. 159.

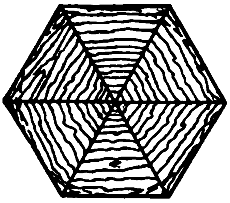


Fig. 160.

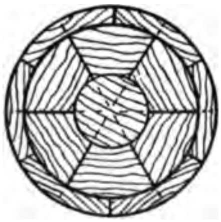


Fig. 161.

In other words, in all glued-up rims, no two joints should be directly over each other. All joints must be so *broken* and so distributed as to give the greatest possible strength to the rim. In the present case, our pattern is so small that it is only necessary to use a thin board, ¼ inch in thickness for each half of the web. After sawing to 6½ inches in diameter, ½ inch for turning, a block ½ inch in thickness is glued on the center of each to form the hub; and six segments 1¼ inches wide and ½ inch in thickness, are glued around on the outer surface of each to form the rim and groove, as shown in Fig. 162.

Care must be taken to place the segments so that the grain of the web will be crossed by two of the segments as shown in the drawings.

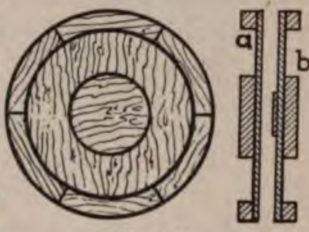


Fig. 162.

On the second half *b* of the pattern, a thin circular block ¼ inch in thickness is glued on the inside opposite to the hub block, to form the projection (⅛ inch) which will keep the two halves of the pattern in alignment, as shown in the cross-sectional drawing in Fig. 159. Having glued up the stock as described, and as shown in Fig. 162, the outside must be planed to a level surface, or so that the six segments forming the rim and the center hub block will be in the same plane.

The half pattern is now screwed on the screw chuck of the lathe as illustrated in Fig. 163, and the inside, or the parting face *c*, is turned perfectly straight and true. The edge is turned down to 6 inches in diameter, and the quartered circle shown by the dotted lines is carefully shaped. A template, made as shown at *d*, will assist greatly at this stage of the work. A recess is turned at the center, and in the face of *a*, Fig. 159, 1⅓ inches in diameter and ⅛ inch deep, to receive the corresponding projection on the half pattern *b* which is to keep the two halves in alignment.

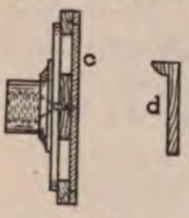


Fig. 163.

The half pattern *a*, is now removed from the screw chuck, and the second half *b* is screwed on and turned in the same manner except that the central projection is carefully turned to fit in the recess in *a*.

Before removing *b* from the chuck, test by trying the second half *a*, and change *b* until a perfect fit is obtained between the two halves, not only in the central recess and projection, but also in the two curves which form the semicircular groove of the rim. A cross-section of the pattern at this stage of construction is shown in Fig. 164.

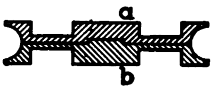


Fig. 164.

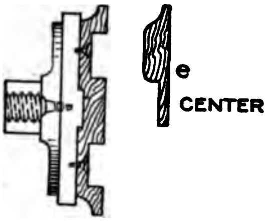


Fig. 165.

A disc or chuck of wood 5½ inches in diameter is now screwed to the iron face-plate, or the screw chuck, and turned off true on the face with a projection ⅛ inch high which will fit into the recess in the middle of the parting face of *a*. This projection will center the half pattern *a* on the face plate, and it can be held in position by two or four short wood screws driven through the web into the wooden chuck as shown in Fig. 165.

Care must be taken to place the screws in such a position that the screw holes will be cut or bored out when making the four or six openings 1 inch in diameter in the finished web of the pulley.

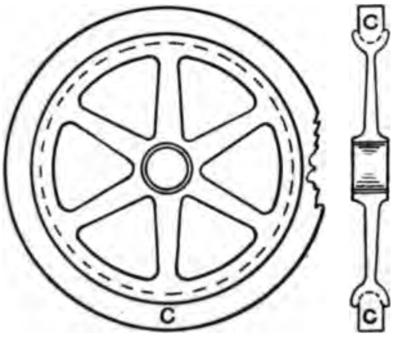


Fig. 166*a*.

The screws must be small and slender and the heads well countersunk out of reach of the turning tools. The face of the half pattern is now turned to the required shape, the template shown at *e* in Fig. 165, being used for the purpose. Having finished with fine sandpaper, remove the half pattern, and turn off the projection on the center of the wooden chuck; turn a recess instead to receive the projection on *b*, and proceed with this second half as with the first. If the wood has been well seasoned, and the work carefully done a perfect 6-inch sheave pulley pattern will be obtained, such as is shown in Fig. 159.

The pattern for a sheave pulley has been explained because it embraces so many profitable points and conditions, not only in gluing and building up, but especially in chucking and turning, all of which must be done with great care and accuracy.

The 1-inch holes in the web are bored out with a 1-inch *center bit*, which, when well sharpened, will not split or splinter the thin webs of the two halves of the pattern, if care is taken to reverse the bore from the opposite side when the point of the center bit comes through. The holes should be given a slight draft as shown in Fig. 159, with a small half-round cabinet file. When very large sheave pulleys, having arms, are to be made, such as are common for power transmission by rope or cable, the patterns are not halved but are made in one piece and the groove is *cored* around the rim. Such a pattern is illustrated in Fig. 166*a*, with a wide core print *c c* extending entirely around the periphery of the pattern.

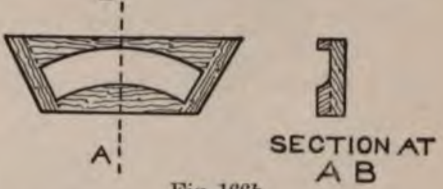


Fig. 166*b*.

A segmental core box is made for one sixth or one eighth the circumference of the wheel, as shown in Fig. 166 *b*, and here again only half of the core box for a full core is needed. When coring the rim as above, the core print must be made wide, at least two to three times the depth of the groove, so that the core may rest firmly and remain in position without tilting while the metal is being poured into the mould.

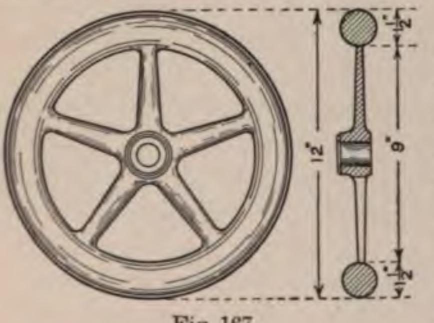


Fig. 167.

The 12-inch hand wheel, Fig. 167, with five arms and a round rim finished to $1\frac{1}{2}$ inches in diameter, will also serve as a good illustration of pattern construction. On the rim of the pattern, $\frac{1}{16}$ inch over all its surface must be allowed for *finish*, making the diameter of the rim of the pattern $1\frac{5}{8}$ inches, and the outside diameter of the pattern $12\frac{1}{8}$ inches, while the inside diameter of the rim will be $8\frac{7}{8}$ inches

The rims of such patterns are usually turned in two halves. A wooden chuck, in this case a plain board 12¾ inches in diameter, and ⅞ inch to 1⅛ inches in thickness, is screwed to the iron face-plate of the lathe, and turned true on the face and on the edge to 12½ inches in diameter. Ten blocks 2½ inches long, 2 inches wide, and ¾ inch in thickness are glued radially at equal distances around the face of the chuck as in Fig. 168. These blocks are turned even with the edge of the chuck, and the faces are also turned off true and straight so as to form a joint with the first row of rim segments.

The segments, ten in number, five for each layer, are sawed from a ½-inch board, and should be 2 inches wide.

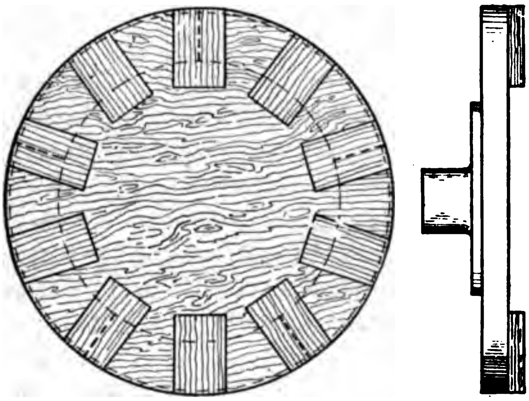
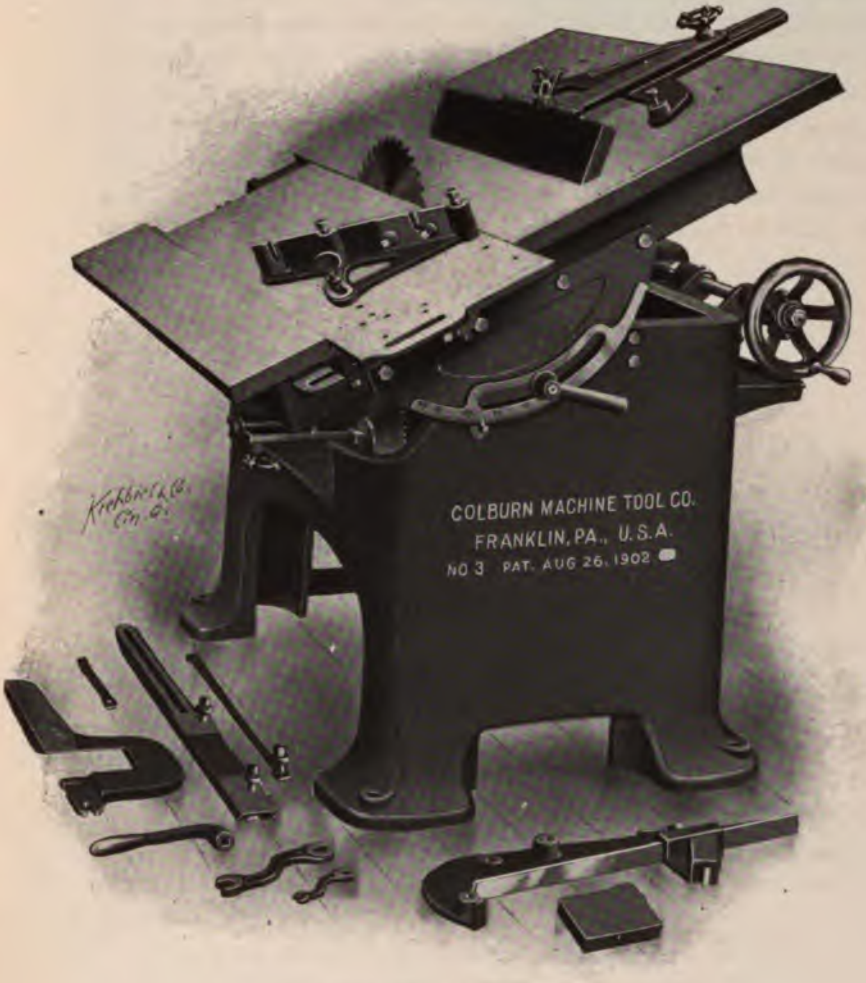


Fig. 168.

Five of these are carefully fitted and glued to the face of the blocks, as shown by the dotted lines in the drawing; and when the glue is dry the chuck is returned to the lathe, and the face of the segments turned flat and true to receive the second row, which is fitted and glued to the first.

Small hand screws must be used, three on each segment, to press the first layer to the blocks, and again to press the second layer to the first. The joints of the second layer must be over the middle of the alternate blocks from the joints of the first, so as to break joints with the first. When the glue is dry, place the chuck in the lathe, and turn the half rim thus constructed to a true semicircle with an outside diameter of 12⅛ inches and an inside diameter of 8⅞ inches, using a semicircular template of sheet zinc or copper to test by while turning.



UNIVERSAL SAW TABLE.
Coburn Machine Tool Co.

When turned and sand-papered, cut from the block of the chuck by using a ⅛-inch parting or cutting-off tool, care being taken to cut close to the segments forming the half rim. Turn off the face of the blocks on the chuck true and straight a second time, and construct and turn the second half of the rim in the same way as described for the first; but great care must be taken to make the two diameters, outside and inside, of each half exactly alike, otherwise the work on one half will be lost. As it is difficult to hold these two half rims for planing and fitting together, a concave and semicircular groove turned in the face of a second board, or chuck, in which they can be laid while being planed or fitted, will be found useful.

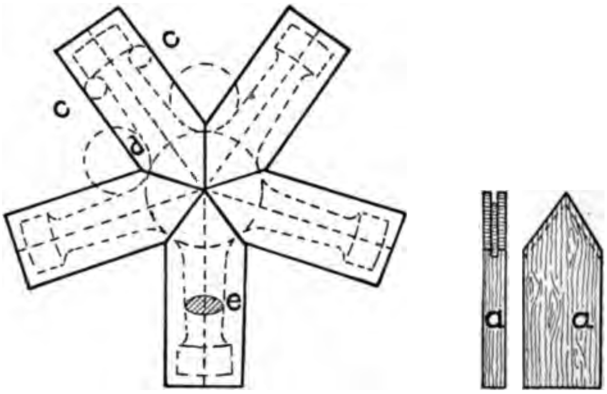


Fig. 169.

In all rim work of this kind the circular segments should be cut lengthwise with the grain of the wood, the object being in this construction, to do away, as much as possible, with all end wood.

While waiting for the separate layers of glued segments to dry, the arms should be made so as to be ready for the two half rims when completed.

The arms in this case should be made ⅝ inch in thickness at the hub and ½ inch in thickness where they enter the rim of the wheel. The construction is as shown in Fig. 169.

Five pieces, each 5¾ inches long, 2⅛ inches wide, and ⅝ inch in thickness are necessary. After being carefully fitted on the trimmer, a saw kerf $\frac{5}{16}$ inch deep is cut in each joint (*a*, Fig. 169), into which a thin tongue of wood is inserted and glued, the tongues serving as tenons to hold the arms together. After fitting, and before grooving with saw kerf, the joints must be glue-sized and, when dry, carefully scraped smooth with a sharp chisel.

The grain of the wood in the tongues must run at right angles to or crosswise of the joint to insure the greatest strength.

When glued together and dry, from the center or intersection of the five pieces, mark with dividers set to a radius of 5¼ inches, and cut off the ends of the arms so that they will project each halfway into the rim.

From the same center describe a circle 3⅛ inches in diameter, forming the web of the arms; and from this 3⅛-inch circle, taper the arms to ½ inch in thickness at the ends, care being taken to plane the same amount from each side, and to dress the arms evenly so that they will revolve in the same plane. This being done, from the center describe arcs on the outer ends of the arms, with a radius of 4⅜ inches (8¾ inches diameter, which is ⅛ inch less than the inside diameter of the rim), and divide the imaginary circle thus formed into five equal parts with the dividers. Draw radii from the points thus obtained, to the center. These radii will be the central lines of the arms, as shown by the dotted lines in Fig. 169.

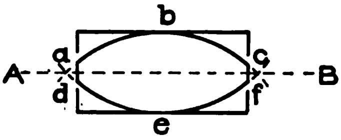


Fig. 170.

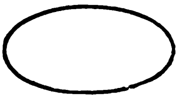


Fig. 171.

On each side of the intersection of the radii and outer circle, measure ½ inch to the right and left, and on the circle denoting the circumference of the web, mark 11/16 on each side of the radii; connect the points thus obtained, and the result will be five arms 1⅜ inches wide at the web and 1 inch wide at the rim, as shown in the drawing. The ends of the arms which enter the rim should be, in this case, 1¾ inches wide, and the sides are drawn parallel to the radius which marks the center of each arm. The curves which connect the arms at the hub must be drawn of such radius as to make the curve tangent to the circle forming the extremity of the web, and also tangent to the sides of the two connected arms as shown at *d*. The small circles at the intersections of the arms with the rim, must be tangent to the edge of the arm and to the circle ($8\frac{3}{4}$ inches diameter) which marks $\frac{1}{16}$ inch less than the inside diameter of the rim as shown at *c c*.

Having laid out the arms as above, and as shown in the drawing by the dotted lines, saw them to shape and round them up to an elliptical form as shown in the cross-section at *e*, Fig. 169. The finished shape of the arm at any point in its length, is found by drawing a cross-section of the arm at that point, as in Fig. 170.

Divide the cross-section equally by the line A B; measure $\frac{1}{16}$ inch; as at *a c d f*; and with dividers adjusted so as to be tangent to the sides of the cross-section of the arm, and to pass through *a c* and *d f*, draw the curves *a b c* and *d e f*.

After filing and working off the sides of the arms to these curves, the angles at *a c d* and *f* are carefully rounded with sand paper, care being taken not to lessen the width of the arm at any point. The result will be as shown in Fig. 171, which gives a strong, firm edge to the arm, and one which will not break or splinter off while being rammed up in the sand.

The arms thus shaped and finished are cut or *let* $\frac{1}{4}$ inch into each half of the rim, and great care must be taken to keep them central with the rim. Before marking the rim for the mortises which will receive the ends of the arms, test their positions with the dividers, spacing from the center of the arms to the outside edge of the rim, and moving the arms until a central position is obtained; after which, with the point of a knife or awl, scribe around the end of each arm, and proceed to cut, with a chisel, the mortises $\frac{1}{4}$ inch deep into each of the half rims, and so cut and fit that the two pieces of the rim may meet and form a close joint, after which they are glued and clamped together over the arms with hand screws.

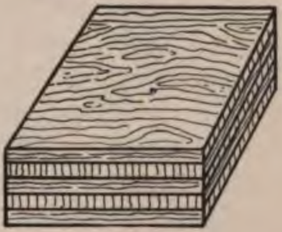


Fig. 172.

The hubs are next turned, each from a solid block, or better from thin pieces $\frac{1}{4}$ inch to $\frac{3}{8}$ inch in thickness, each thin piece being placed crosswise on the other, as shown in Fig. 172. The hubs must be turned with a draft or taper of $\frac{3}{8}$ inch to 12 inches, and have a curve of $\frac{1}{4}$-inch radius at the base where they unite with the arms. After gluing on the hubs, smooth off all connected parts

d hub, and finish with three coats of shellac, sand-
between each coat, as already described for other

of patterns for special pulleys enters largely into
ny pattern shops. In these patterns the rims are
nents ⅜ inch to ½ inch in thickness.

rate this work fully, let us take up the successive steps
ction of a countershaft pulley 20 inches in diameter
h face, made to fit a shaft 1¾ inches in diameter.
n for such a pulley is shown in Fig. 173. The diameter
of the arms is 5 inches, and the diameter of the hub 3½
s at each end and tapering to 3¾ inches in diameter at the

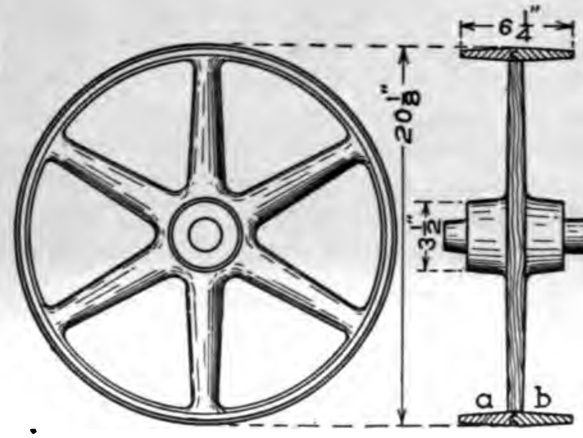


Fig. 173.

If the rim is to be finished on the face and edges only, $\frac{1}{16}$ inch must be allowed for turning, making the outside diameter of the pattern 20⅛ inches, and the width of the face should be 6¼ inches.

In addition to $\frac{1}{16}$ inch for finish, the draft on the outside of the rim, from each edge to the center, should be in the ratio of ⅛ inch to 12 inches, and on the inside of the rim the draft must be ⅜ inch to 12 inches.

The thickness of the rim at its edges will be $\frac{5}{16}$ inch, and with outside and inside draft added, its thickness at the arms will be about $\frac{7}{16}$ inch. The inside diameter of the rim at the arms will be nearly $19\frac{3}{32}$ inches. This pulley should have six straight arms

¾ inch in thickness at the hub and ⅝ inch in thickness at the rim. The width of the arms at the web should be 1¾ inches and at the rim 1½ inches exclusive of the connecting curves at web and rim. Six pieces 10½ inches long, 2¾ inches wide, and ¾ inch in thickness, must be carefully fitted as shown in Fig. 174.

After fitting, the connecting joints are glue sized, and when dry carefully scraped smooth with a sharp chisel, and a saw kerf $\frac{5}{16}$ inch deep cut in each. The tongues used for tenons in these kerfs should be a little less than ⅝ inch long, the grain of the wood running always at right angles to the line of the joint to give the greatest strength to the tenons.

The six pieces should be glued in two groups of three pieces each; and when dry, these two groups can easily be refitted, if necessary, and glued.

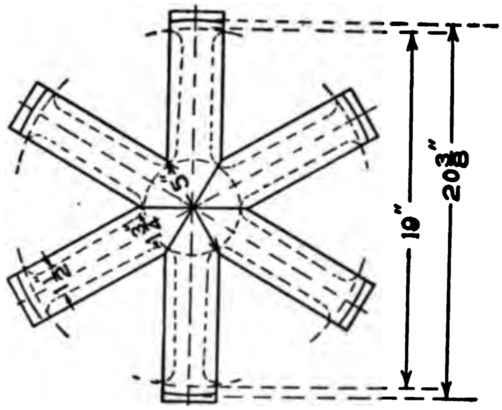


Fig. 174.

The next step is to draw, from the center formed by the intersection of the six pieces, a circle 5 inches in diameter, representing the web of the arms, and, near the extremities of the pieces, the arcs of a circle 20⅜ inches in diameter, representing ¼ inch greater diameter than the outside diameter of the rim. Carefully divide these last arcs into six equal spaces with the dividers, bringing the points thus obtained as nearly to the middle of the six arms as possible; and from the six points thus spaced, draw radial lines connecting them with the center or intersection of the six arms. These radial lines (shown dotted in the drawing) will be the center line of each arm.

Saw off the ends of the arms on the above 20⅜-inch arcs, and from the center again draw on the six arm-pieces a third circle, whose diameter should be at least ⅛ inch less than the inside diameter of the rim, in this case 19 inches. On these arcs measure ¾ inch on each side of the center line, and on the circle representing the web, measure ⅞ inch on each side; connect these points from web to rim, and the arms will be 1¾ inches wide at web, and 1½ inches at the rim.

These lines are shown by the dotted lines in Fig. 174. The width of the ends of the arms passing through the rim should be about 2½ inches, and the sides drawn parallel with the center line of the arm, as shown for hand-wheel arms in Fig. 169. The radius of the circle connecting the sides of the arms and the web, must be such as to be tangent to the edges of the two connected arms, and also tangent to the circle marking the diameter of the web.

The smaller curve connecting the two edges of each arm with the rim must be of such radius as to be tangent to the arm and to the 19-inch arcs which mark the inside of the rim (less ⅛ inch). All these lines are shown dotted in Fig. 174. The arms are now ready for sawing to shape on the band or scroll saw, care being taken to saw just *outside* of the lines so that each arm may retain its full size and width.

After sawing to shape, the edges must be dressed smooth and free from all irregularities of the sawing.

Next, from the web circle, taper the arms to ⅝ inch in thickness at the extreme ends, care being taken to see that the taper of both sides of the arms is uniform from the web circle to the rim.

The shape of the arms should be elliptical or nearly so, and a cross-section at any point in an arm may be obtained in the same manner as described for the hand wheel shown in Figs. 170 and 171, and the methods used for shaping and finishing are the same. For building the rim, a wooden chuck 20½ inches in diameter will be necessary.

A board ⅞ inch in thickness and having a bar 8 inches wide and of the same thickness, well screwed to the back with wood screws will be all that is necessary for a pulley of this size. To the 8-inch bar, the iron face-plate of the lathe is screwed, and the whole turned off true in the lathe, especially the face of the chuck to which the first layer of segments is to be glued.

Strips of heavy paper are often glued between the first layer of segments and the face of the chuck, so that the rim and the chuck may be easily separated when the rim is turned and finished. The paper usually splits, allowing separation without injury to the wood. A better method, however, is to glue twelve blocks, each 2 inches long, 2 inches wide, and $\frac{3}{4}$ inch in thickness, to the face of the chuck, in the same way as that described for the small hand wheel shown in Fig. 168.

When the rim is finished it may be sawed or cut off through the blocks without injury to the chuck and its future use. The segments to form the rim should be six in number for each layer. They should be $\frac{7}{8}$ inch wide, and cut from $\frac{3}{8}$-inch or $\frac{1}{2}$-inch stock, lengthwise with the grain of the board, so as to avoid end wood. The first layer is fitted and glued to the blocks (or to the face of the chuck with paper between), and securely clamped with small hand-screws, three to each segment. When the glue is dry, one hour being sufficient for thin $\frac{3}{8}$-inch segments, place the chuck in the lathe, and carefully turn off the face of the segments true and straight to receive the second layer.

This layer, in turn, is turned off in the lathe and the third layer is glued on, hand screws being used on each layer as on the first, and the joints of the segments so broken that no two will be directly opposite each other, all joints being carried to right or left of all preceding joints, thus securing the greatest possible strength to the rim.

No nails should be used in any work of this description. Having glued on a sufficient number of layers to form half of the rim, turn it to the required external and internal diameters, making the thin or outer edge of the half rim next to the chuck, and carefully giving the required draft to each side.

Before removing the half rim from the chuck, turn a groove $\frac{1}{16}$ inch to $\frac{1}{8}$ inch in depth and of about one third of the width of its thickness in the edge of the rim, as shown in Fig. 173 at *a*. Remove the half rim from the chuck (or cut from the blocks), and proceed to build up and to turn the second half *b* in the same way as the first. Instead, however, of turning a groove on its edge, carefully turn and fit a small projection, or tongue, to the groove in the half *a*, as shown in the drawing. If the work has been done with care and accuracy the groove and tongue will bring the two halves into perfect alignment.

The arms are next fitted centrally to each half of the rim, and the two halves glued together over the arms in the same way as described for the hand-wheel pattern. The projecting ends of the arms are cut off and shaped to form a part of the outside of the rim. The internal curves of the arms at the inside of the rim are also filed and shaped down so as to form true curves without cusps or irregularities. The hub is next glued up in cross-layers as described in Fig. 172, turned out, and glued centrally on each side of the arms.

The pulley being intended for a $1\frac{3}{4}$-inch shaft, the core prints x and y, Fig. 173, should be $1\frac{1}{2}$ inches in diameter, which will give $\frac{1}{8}$ inch of metal for boring out to fit the shaft. The two core prints (Fig. 175) should be turned separate from the hubs, and loosely attached with a pin $\frac{3}{4}$ inch in diameter, and $\frac{3}{4}$ inch long, into each half hub, so that other sizes may be used for larger or smaller shafts. The two half hubs are often made loose so that they may be changed for larger or smaller hubs as may be required for different sizes of shafts. In such cases they are attached centrally to the arms as described for the core prints.

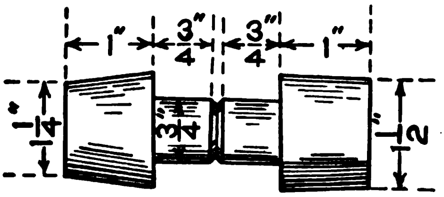


Fig. 175.

A second method in the construction of such special pulleys is as follows:

The half rim having been glued up as described, the *inside only* of this half is turned to the required dimensions and draft, sand-papered, and finished, the width of the half rim being made in this case $\frac{5}{16}$ inch less than the half of the face of the completed pattern. The arms are carefully centered and glued to this half rim; and the intervening spaces between the ends of the arms are filled in with six segments $\frac{11}{16}$ inch in thickness, which, when glued and dry, are planed, *not turned*, true and even with the surface of the arms.

A layer of segments of the regular thickness is fitted and glued on over the arms, and layer after layer continued until the full width of the face of the pattern is reached, thus building the arms directly into their place in the pattern as the rim is glued up. In turning and finishing, care must be taken not to strike the arms with the tools while turning out the inside of the outer half of the rim.

This method will be found convenient for all pulleys of moderate width of face; but as the spaces between the arms cannot be turned out, great inconveniences in reaching these places will be found when the face of the pulley is twelve or more inches in width. These spaces must be dressed out by hand.

The instructions regarding the construction of the last three patterns should be studied carefully, because the general points involved enter largely into the construction of patterns of all kinds, and especially for all work having arms with circular rims.

When pulleys of standard sizes for line shafting are manufactured in quantities, a skeleton pattern consisting of hub, arms, and an independent iron rim is used. This iron rim is of moderate width but may be used for obtaining any width of face desired.

Wooden patterns complete in themselves, as that described for Fig. 173, are used for all special pulleys on machines when the required sizes and widths, as also hubs and connections, are irregular and designed only for the special machine, so that the making of pulley patterns is important in nearly all foundries and pattern shops.

Where the iron rim is to be made, the same care is necessary in the building up of the original wooden pattern. It must be remembered that before the final casting is obtained, two shrinkages will take place; first, the shrinkage of the original casting from which the iron ring is turned, and then the shrinkage of the casting made from this pattern. In addition to this, there must be the allowance for turning the ring both inside and out and for the turning of the outside pulley rim. Suppose the pattern is to be made for a pulley two feet in diameter. The usual allowance for a single shrinkage is made by the shrinkage rule. In this case the allowance must be doubled. Thus in the above pulley, the diameter of the wooden pattern becomes $24\frac{1}{4} + \frac{1}{4} = 24\frac{1}{2}$ inches, standard rule measurements, or $24 + \frac{1}{4} = 24\frac{1}{4}$ inches, shrinkage-rule measurements. As a very smooth surface, free from holes, is required, $\frac{1}{4}$ inch in diameter, or $\frac{1}{8}$ inch all around, must be allowed for outside finish on the iron ring, and $\frac{1}{8}$ inch for finish on the rim of the cast-iron pulley.

The outside diameter of the original wooden pattern is $24\frac{1}{4} + \frac{1}{4} + \frac{1}{8} = 24\frac{5}{8}$ inches, with shrinkage rule. If the final thickness of the pulley rim is to be $\frac{3}{8}$ inch, this, with the allowance of $\frac{1}{8}$ inch for turning out the inside of the iron ring, makes the inside diameter of the wooden pattern 23 inches, and the thickness of the wooden rim $\frac{13}{16}$ inch, all shrinkage-rule measurements.

This wooden-ring pattern must be built up on a chuck, as described for the 20-inch × 6-inch pulley, the segments, six in number for each layer, fitted, glued, and clamped with three hand screws to each segment until a width of $6\frac{1}{2}$ inches is reached.

It is then turned to the above dimensions, *without any draft*, and sent to the foundry, where it may be used for obtaining an iron rim of any required width by first ramming the sand about the pattern, partly drawing it, and then ramming again to a new level.

The casting thus obtained is then turned to the dimensions called for by an ordinary pattern; that is to say, the shrinkage-rule measurements would leave it $23\frac{1}{4}$ inches in diameter on the inside and $24\frac{1}{8}$ inches on the outside, permitting a final finishing of the outside of the rim of the pulley to a diameter of 24 inches. When this is done, two $\frac{3}{8}$-inch holes should be drilled near one edge of the rim and diametrically opposite each other, into which hooks may be inserted for drawing the pattern. This rim should also be turned straight and without any draft.

The arms are usually made with a wooden pattern, which has a dowel-pin hole on each side at the center for attaching the hubs that are loose, the object being to change their length and diameter to suit the width of the rim and the diameter of the shaft upon which the pulley is likely to be placed.

The arms of all pulleys should be straight because of the greater strength given to the pulley as a whole, the driving and resisting power being at least one-third greater than in a pulley of the same dimensions having curved arms. Curved and shaped arms of all kinds are now used only for ornamental purposes and for very light work.

The arms should be six in number, except for very small pulleys, when five and even four are often used. The dimensions of the arms vary greatly, depending on the purpose for which the pulley is to be used, and the weight of the machinery to be driven.

For the beginner the following formula is safe to follow:

$$b = \sqrt[3]{\frac{d \times w}{n \times 8}}, \quad \text{in which}$$

$b =$ the breadth of the arm at the outer end,
$d =$ the outside diameter of the pulley,
$w =$ the width of the rim,
$n =$ the number of arms,

all dimensions being taken in inches. Thus, for a pulley 24 inches in diameter with a rim 6 inches wide and fitted with 5 arms, the formula becomes·

$$b = \sqrt[3]{\frac{24 \times 6}{5 \times 8}} = \sqrt[3]{3.6}$$

Hence, $b = 1.53$ inches or 1½ inches.

The width of the arm should be one-fourth greater at the hub than at the rim. The thickness at the hub and rim should be one-half the width, and the section should be elliptical. The arm just calculated then becomes,

1½ inches wide at rim,
¾ inch thick at rim,
1⅞ inches wide at hub,
1 inch thick at hub.

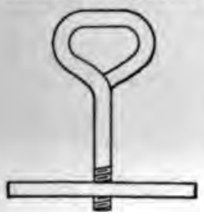
For the skeleton pattern last described, the common method of constructing the pattern for the arms, is to make each arm of a separate piece of wood with the grain running in the general direction of the arm, and to fasten them together at the center with glue and a flat plate or disc, which can also be used as a rapping plate. This pattern need be parted only in the case of very large and heavy wheels. For all ordinary work it can be made in one piece and moulded as directed in connection with the hand wheel, Fig. 167.

HUBS.

An ordinary rule is to make the outside diameter of the hub twice the diameter of the shaft. The two half hubs (one on each side of the arms) are usually loose and are held central by a single dowel pin. Their diameters are adapted to the size of the shaft upon which the pulley is to run, and the length is proportioned to the width of the rim as well as its diameter. The length of the hub should be about two-thirds the width of the rim except in the cases of tight and loose pulleys, where the hub should be a trifle longer than the width of the rim. It may then project about $\frac{1}{8}$ inch on the sides in contact, and $\frac{1}{4}$ inch on the outside.

RAPPING PLATES.

In the description of the making of the pulley pattern, the ring serving as a binder for the hub is spoken of as a rapping plate. When a pattern is imbedded in the sand, the latter is closely compressed all about it, and slightly adheres. The moulder is, therefore, in the habit of rapping the pattern gently in order to loosen it in the sand before attempting to draw it. If the pattern is not provided with a metal plate, the moulder will drive the sharp point of a lifter into the wood and strike it alternately on opposite sides and at the same time use it to lift the pattern from the sand. This mars the pattern and will in time ruin it. The rapping plate, shown in the engraving, is a piece of thin metal $\frac{1}{8}$ to $\frac{3}{16}$ inch thick, inserted so that it is flush with the parting face of the pattern and is held by wood screws with countersunk heads. These plates are drilled and tapped for a $\frac{3}{8}$-inch screw and should be the same for all patterns in the foundry so that one set of rods can be used interchangeably. The method of using is to screw the rod into the plate and rap it gently to and fro until the pattern has been loosened, when it may be lifted. For small patterns, one rapping plate will be sufficient and this should be so placed that the hole for the lifting rod comes directly over the center of gravity of the piece. This will prevent tilting of the pattern as it is lifted from the sand. For medium sized patterns, two rapping plates should be provided, so that the pattern can be raised from two opposite sides. For still larger patterns three or four rapping plates are used; the object being to give such perfect control when drawing that there can be no tearing away of the sand.



Rapping Plate.

METAL PATTERNS.

Metal patterns are extensively used where either one of two conditions prevail: first, where the character of the work is so light and delicate that a wooden pattern could not hold together, as in ornamental castings; and second, where such a large number of castings are to be made that the wooden pattern would not last long enough to complete the work. Metal patterns may be made of iron, brass, or aluminum. The latter metal is coming into great favor because of its light weight and its freedom from corrosion by the moist sand. These patterns should be given a light coating of shellac varnish, but it is not absolutely necessary. Where iron is used, some preservative must be put upon the surfaces to protect them from rust. The best method is to warm the metal and rub it with a rag dipped in melted beeswax. This excludes the air and leaves a smooth surface so that it is easily drawn out of the sand. This, however, is not a very durable protection; the more common method is to use a shellac varnish. In order that the varnish may adhere, the metal should first be wet with a solution of sal ammoniac, and, when dry, sand-papered and shellaced.

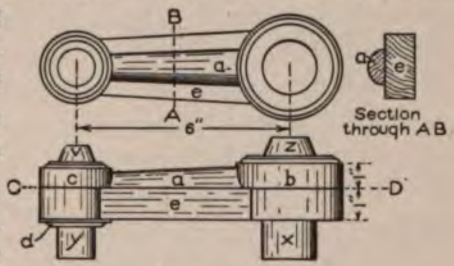


Fig. 176.

In the small 12-inch crank pattern shown in Fig. 176, is shown a very simple *one-piece* pattern. In spite of its simplicity it requires considerable skill in shaping and in obtaining the necessary draft. The parting of the mould will be on the line C D. The piece *e*, for the main body of the pattern, should be made rectangular in form, and laid off with center lines from which the positions of the bosses *c*, *b*, and *d*, and the core print *x* may be drawn on the upper and lower sides respectively. The bosses are turned on the lathe to the required form, and given a draft of ¼ inch to 12 inches. After *b* and *c* have been glued on, the part *e* is sawed to shape, sawing close to, but not touching *b* and *c* with the saw. The thin boss *d* is next glued in place, after which *e* is filed and dressed to the required shape and even with *b* and *c*, giving it the same draft, ¼ inch to 12 inches, but in the opposite direction from the parting line C D. The rib *a* is next turned on the lathe, and one side split off on the band saw, after which it is fitted between *b* and *c*. The core prints may be turned with a small tenon on one end to fit into holes bored in the pattern, or they may be turned flat on both ends and nailed on. Core prints *x* and *x* must have no more draft than is given to the body of the pattern ($\frac{1}{4}$ inch to 12 inches); but *z* and *z*, which will be moulded in the cope, must be $\frac{1}{4}$ inch less in diameter at the upper end than the diameter at the base.

The heavy engine-crank pattern illustrated by Fig. 177, differs but little in general construction from that shown in Fig. 176, except that, being large and heavy, it must be built up out of thin stock, as shown in the drawing.

The stock is first glued up to the necessary thickness, after which it is laid out and sawed to shape as one piece, the saw table being tilted slightly to give the required draft, which in this case must not be more than $\frac{1}{8}$ inch or $\frac{3}{16}$ inch to 12 inches.

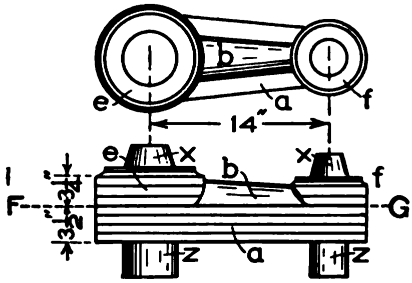


Fig. 177.

The bosses *e* and *f* are also glued up out of thin stock, the pieces being crossed so that the grain of each will be at right angles to that of the other, as illustrated in Fig. 172, after which they are turned with a draft of $\frac{1}{4}$ inch to 12 inches, and fitted to *a*.

Of the four core prints only *x* and *x* will have excessive draft, as explained in connection with Fig. 176; *z* and *z* must have no more draft than the body of the pattern. The parting of the mould, as in the former case, will be on the line F G.

In Fig. 178, is illustrated a finished cast-iron *disc crank* for an engine of 12-inch stroke. This crank is finished on the face, on the outer edge, and on the end of the hub. It is bored out $3\frac{1}{4}$ inches to fit on the engine shaft, and $2\frac{1}{4}$ inches to receive the wrist pin. An addition of $\frac{1}{8}$ inch must be allowed on the pattern for finish of the face, and the same on the end of the hub; $\frac{3}{16}$ inch will be sufficient to add for finish on the outer rim, making the

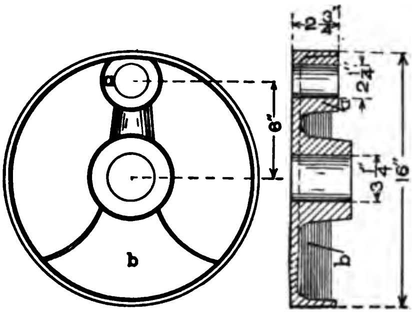


Fig. 178.

diameter of the pattern $16\frac{3}{16}$ inches, and the thickness of the disc $\frac{9}{16}$ inch. A sectional view of the pattern is shown in Fig. 179.

The disc for this pattern must be made of two thicknesses of sectors, six in number for each thickness, which, after being fitted, glue-sized, and glued together, are planed off true on both sides, and glued on each other so as to break joints, as shown in Fig. 180. When dry, the disc thus obtained is sawed to a diameter of $16\frac{1}{2}$ inches and glued to the wooden chuck on the iron face-plate of the lathe with small sectors of thick paper between, or else glued to small blocks on the chuck, from which, after turning, it can be cut as illustrated in Fig. 168. The rim is now built up on the disc out of segments $\frac{3}{8}$ inch or $\frac{1}{2}$ inch in thickness, as directed for the 20-inch pulley (Fig. 173), with not less than six segments to each course. The hub is glued up as described, and, after gluing on the disc, the whole is turned to the required size and shape.

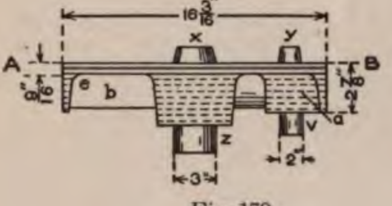


Fig. 179.

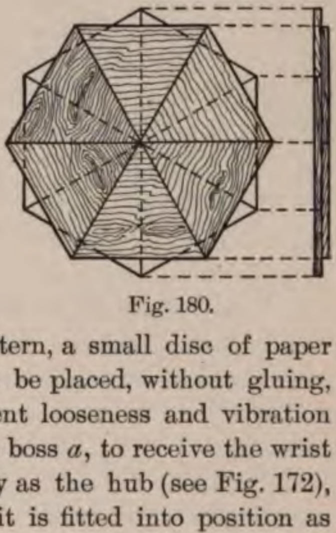


Fig. 180.

In the case of this disc-crank pattern, a small disc of paper (or a block, if blocks are used) should be placed, without gluing, under the center of the disc, to prevent looseness and vibration while being turned in the lathe. The boss *a*, to receive the wrist pin, must be glued up in the same way as the hub (see Fig. 172), and turned on the lathe, after which it is fitted into position as indicated in Figs. 178 and 179. The counter-weight *b* is next shaped from a single piece, or it may be glued up of several thicknesses of $\frac{1}{2}$-inch stock. In sawing this block to shape, the band-saw table should be tilted so as to give it a draft of $\frac{3}{8}$ inch to 12 inches. Give the inside of the rim, the hub, and the boss *a*, the same draft, but the outside of the rim should not have a draft of more than $\frac{1}{8}$ inch to 12 inches.

When turning on the inside of the rim, a *fillet* or curve must be made where it joins the disc, of ⅜-inch radius, as shown at *e*, Fig. 179. The same curve must be turned at the base of the hub. Around the counter-weight block, and also around the wrist boss, a ⅜-inch leather fillet can be used.

For convenience in moulding, the two core prints *x* and *y* should be turned with a tenon ¾ inch in diameter and ¾ inch long, to fit into the holes in the face of the disc, so that they can be removed when the pattern is laid on its face on the moulding board. The core prints *v* and *z* are turned without tenons, being glued and nailed in position.

FILLETS.

The fillets spoken of in connection with Fig. 179, are used in all except the most simple patterns. They consist of a small quarter curve varying in size from ⅛ inch radius upward, depending on the size of the pattern and the room they can be allowed to occupy. They should be placed in all corners, wherever possible, so that there may be no sudden changes in the direction of the surface of the casting, which causes weakness, the fillets adding greatly to the strength of the casting.

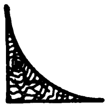
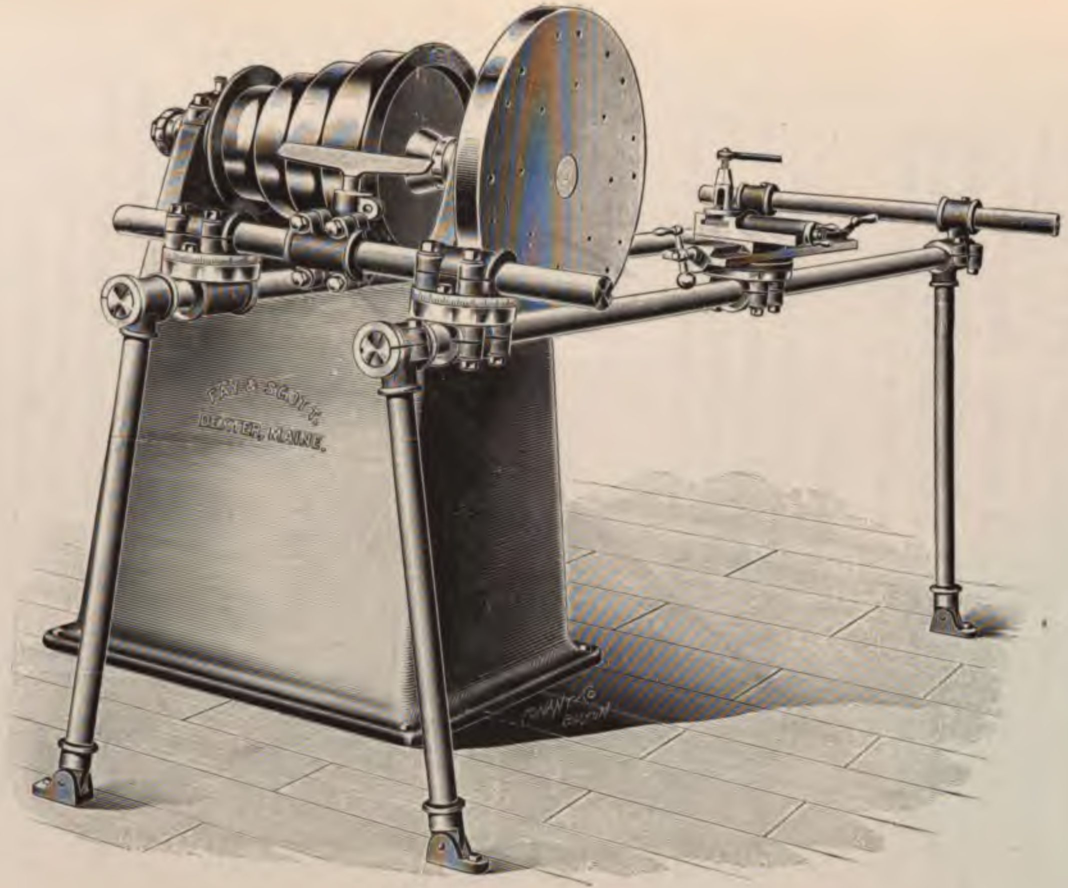


Fig. 181.

These fillets are made in various ways, the wooden fillet, cut as in Fig. 181, being commonly used for all long, straight angles, or for very flat curves to which it can be bent.

For irregular angles and for short radius curves, beeswax was formerly used, but the modern *leather fillet* has almost entirely superseded beeswax and other material for this purpose. It is easily applied, shaping and adapting itself to any and all positions and angles. It can be bought in all sizes from ⅛ inch up, the sizes running by sixteenths. The method of applying it is to cut it to the necessary length and lay it on a board where the glue can be easily brushed over it. It is then laid in the angle and rubbed into position by means of a dowel rod, the end of which must be rounded off as shown for the connecting dowel pins of a parted pattern, Fig. 152. The dowel rod must be of such size as to impart the required urve to the soft, pliable leather fillet. As soon as the fillet is ubbed into position all surplus glue must immediately be wiped off before it sets. This is easily done with a small piece of waste



FACE PLATE LATHE.

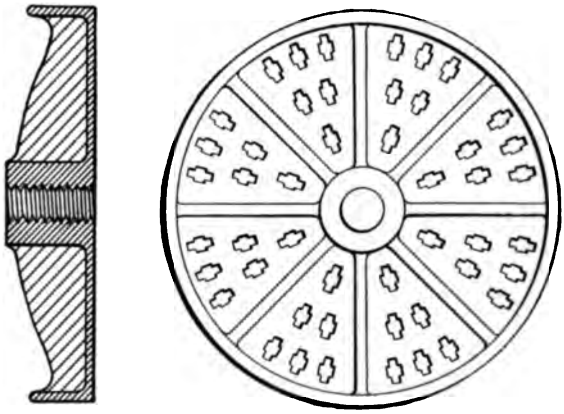
Fay and Scott

or a rag dipped in the hot water of the outer glue-pot and wrung out nearly dry, care being taken not to wet any part of the pattern more than can possibly be helped, after which it must at once be wiped dry.

These leather fillets will be found more pliable and more easily placed and rubbed into position if the glue used is first allowed to cool slightly. Very hot glue stiffens and crinkles the leather, causing it to work hard.

FACE PLATE.

It is sometimes advisable to use cores even if it is quite possible to construct the pattern so that it would core its own holes. This is the case where it is desired that the faces of the casting and the holes shall be smooth and as true as possible without expensive machine work. The finished face-plate of an engine lathe illustrated in Fig. 182 is a good example of such work.



a. Fig. 182. *b.*

It will be readily seen that the pattern for this casting could be put in the sand and withdrawn from the mould, leaving the sand standing where the holes are located.

The trouble that arises from this method is due to the fact that when the metal is poured and allowed to flow about the fragile projections that are left to form the holes, the sand washes away, so that the holes in the casting are irregular and much smaller than those in the pattern. For these reasons the holes should be cored, as the core sand is firm and better able to resist the washing action of the flowing metal.

The patterns for such a face plate, a cross-section of which is shown in Fig. 183, should be made as follows: The allowance for finish on the face of the casting should be not less than $\frac{3}{16}$ inch, and the same should be added to the diameter and also to the end of the hub. Having thus determined the thickness and size of the pattern, the disc should be built up of from four to sixteen sectors, according to the size of the plate. If the diameter is between 24 and 42 inches, sixteen sectors should be cut out, each filling an arc of 45°, so that when eight are placed edge to edge they will complete the circle. The thickness should be a little more than one-half the completed thickness of the pattern disc, and they should be laid up so as to form two layers, breaking joints with each other as shown in Fig. 180. When the disc is formed, the hub should be first glued in position, this also being built up of pieces glued together, and the whole attached to a large wooden chuck and iron face-plate of the pattern lathe in the same manner as described for the disc-crank (Fig. 178). The rim is next built upon the disc in the same way as has been described for former patterns. If the face plate is very large, the segments may be $\frac{1}{2}$ inch or even $\frac{5}{8}$ inch in thickness, and to avoid end wood, eight, twelve, or even sixteen, segments may be used for each layer according to the diameter of the rim.

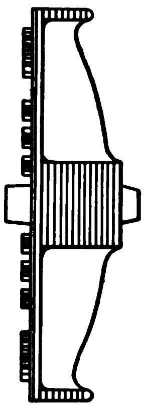


Fig. 183.

The pattern now consists of the disc with the rim and hub in position, but larger than they should be. It is, therefore, placed in the lathe and carefully turned over its whole surface, each part and thickness being brought to the shape and dimensions of the completed pattern, care being taken to turn in a fillet of $\frac{1}{4}$ inch to $\frac{1}{2}$ inch radius, depending on the size of the required casting, in the angles connecting the rim and the hub with the disc. Next put in the ribs; it is not necessary to form these out of built-up material, for each may be cut from a single piece. They should be carefully fitted to form a close joint with the rim, the disc, and the hub, before they are glued in position. When this is done, all angles formed by the rim, ribs and hub with each other should be carefully filleted.

After the fillets are in position, it remains to provide for the coring of the holes. This is done by first laying out upon the face of the pattern the location and size of the holes. It is upon the points thus located that the core prints are placed. Before this is done it must be decided which side of the casting is to be made uppermost.

Where a large, flat surface is to be given a finish, it is desirable that the metal should be as clean and free from sand and blowholes as possible. As the iron has a greater specific gravity than the sand of the mould, all particles of sand that may be washed away and all gases generated, rise to the surface of the molten metal. Those imprisoned by the cooling of the iron form the dirt and blowholes that disfigure the completed casting. In a casting such as the face-plate under consideration, it is desirable, then, that the face should be upon the lower side when the metal is poured. For the sake of convenience in setting the cores, the prints are put upon the face and make their impress in the sand of the drag. They should be glued and nailed in position after the pattern itself has been sand-papered. The core prints for the hole through the center are also put on in the same way.

PIPE CONNECTIONS.

Many patterns which at first may seem to be quite formidable, will, after a little study, resolve themselves into a few very simple parts, nearly all the work for which may be done in the lathe. Of this the tee pipe connection shown in Fig. 184, is a good illustration.

A sectional view of the casting, threaded and having a pipe screwed into the right-hand end, is shown in Fig. 185.

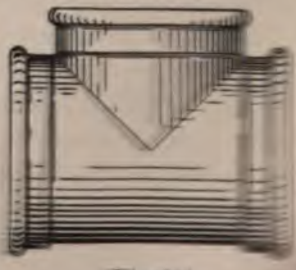


Fig. 184.

The completed pattern for this casting is illustrated in Fig. 186, with its core prints *a*, *a* and *a*, and must be parted [illegible] in Fig. 187. The entire pattern may be made [illegible] as illustrated in Fig. 188. The preparation of the wood for this pattern is similar to that described for the pattern of the brass bearing, Fig. 150; the two halves having the necessary dowel pins inserted, and glued together at the extreme ends only.

When there is not time for the glue to dry, all such *parted* work may be held together while being turned, by having staples driven into the ends as shown in Fig. 188. Indeed, for all large and heavy work this method is to be preferred; two, and even four, staples being used in each end as the size of the work may demand. When the turning is completed, it is only necessary to cut a V-shaped opening into the two halves of *e*, into which the part *f* is fitted and glued. When the glue has set and is sufficiently dry, the joint may be further strengthened by nailing, or by inserting and screwing a thin metal connecting plate flush with the parting side of each half of the pattern. This, however, will be necessary only when patterns are large and heavy, or when unusual strength is required.

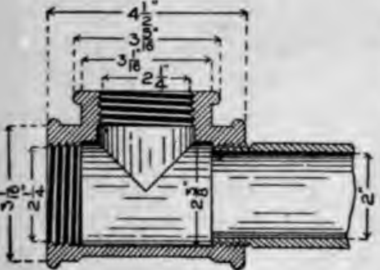


Fig. 185.

The core box for this pattern, as will be seen in Fig. 189, is the usual half box and is made by working out the box in one piece, long enough to make the two parts *a* and *b*. The two parts are united by cutting a V-shaped opening in the part *a* and fitting *b* into it in the same way as described for the pattern. The whole is then glued and screwed to the board *c*, and the two triangular blocks *d* and *d* are glued in the angles to add strength to the completed box. In case the pattern is for a very small pipe, 1½ inches or under, the part *b* may be abutted against the side of *a*, as shown by the dotted line, and the side of *a*

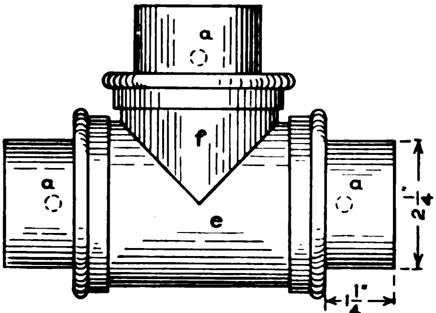


Fig. 186.

at *e* cut away to the same curve as *b*, giving the same results as in the former method.

The pattern for the 2-inch elbow, Fig. 190, is another illustration of how such work may be simplified, and time saved, by doing the greater part of the work in the lathe.

As these elbows are usually cast in large numbers, the pattern should be made double as shown in Fig. 191. To construct the double pattern, a ring is first turned like Fig. 192, a cross-section of which is a semicircle as shown in the lower right-hand corner of the drawing. This ring is cut into quarters, and the four pieces *e*, *e*, *e* and *e* make the quarter turns for the two halves of the double pattern.

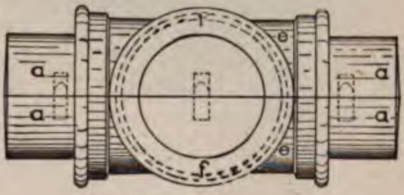


Fig. 187.

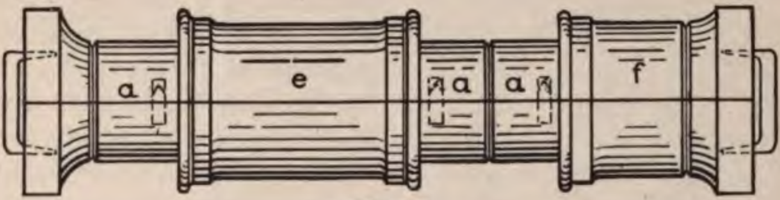


Fig. 188.

The ends, including the core prints and connecting tenons, are turned in one piece as shown in Fig. 193, the stock for which is prepared, with the inserted dowel pins all in position in the same manner as described for the tee pattern, Fig. 188. The quarters, *e*, *e*,

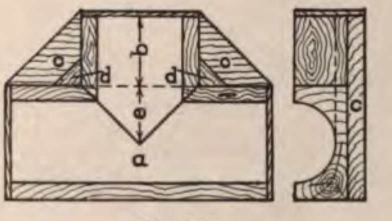


Fig. 189.

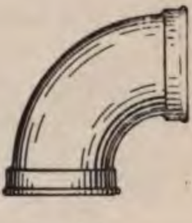


Fig. 190.

e and *e* are clamped together two and two, and the ends carefully bored to receive the tenons which are then glued in position and further strengthened by a wood screw as shown in Fig. 191.

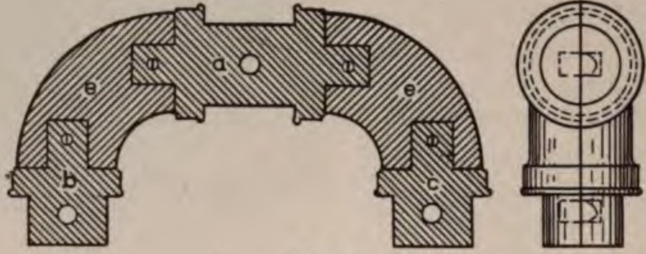


Fig. 191.

In Fig. 194, the core box for this double pattern is shown, and as will be seen the most difficult part of the work can be done in the lathe. Fig. 195 shows two pieces jointed and clamped together which must be screwed to the face-plate of the lathe and turned out to make the two corners *c* and *c*. The three straight parts *d*, *d* and *d* are worked out in one long piece and afterwards cut to the required lengths, after which the five pieces are glued and screwed to the board *a*. The ends *e*, *e* are next put on and the required half core box is complete.

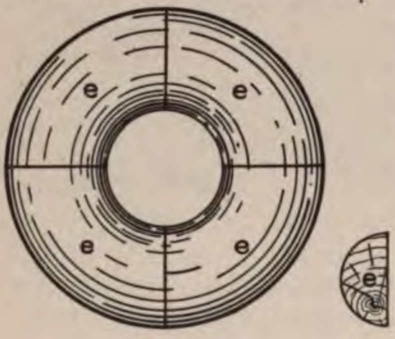


Fig. 192.

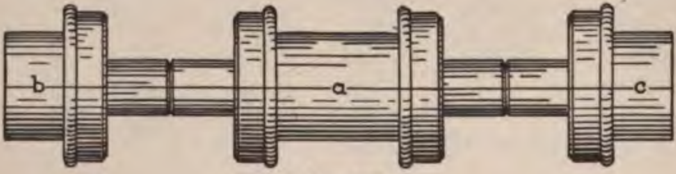


Fig. 193.

Another reason why the pattern for pipe elbows should be made double is that otherwise the core prints would require to be made of great length in order to balance, sustain, and keep the heavy core in position; the tendency being to sag in the middle, or float on the molten iron, and thus make the upper side of the casting too thin, all of which is avoided in the double pattern.

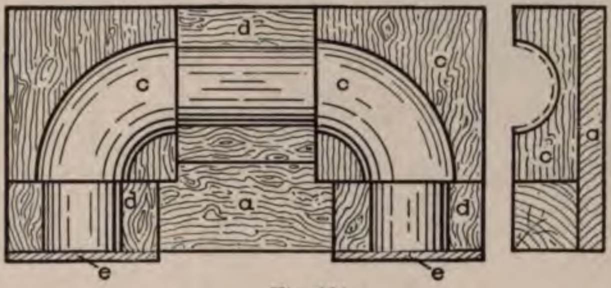


Fig. 194.

A pattern for the return bend, Fig. 196, can be built up and constructed in the same manner as described for the elbow; the semicircular returns, not only for the pattern, but also for the core box, being turned in the lathe, together with the ends and core prints for the pattern. As there will be no middle support for the core in this case, the core prints must be made, as shown in the half pattern, Fig. 197, of sufficient length to balance the heavy semicircular core, and also to keep it in its true position in the mould.

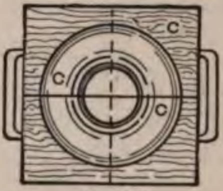


Fig. 195.

The small wood lathe chuck, a vertical section of which is shown in Fig. 198, will serve as a simple illustration of the long *core* print and *balanced* core. The casting must be counter cored; that is, the cored opening must be enlarged at the forward end, adding to the size and weight of that end of the core, which, as

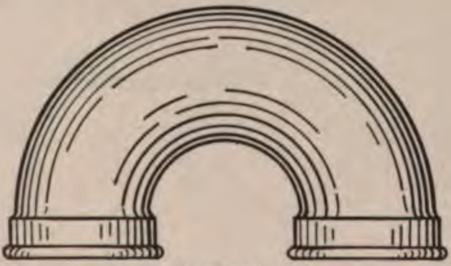


Fig. 196.

will be seen, has no support except that afforded by the extra length of the core at the opposite end. The pattern for this chuck is shown in Fig. 199, and the core print must have a length at least twice as great as the depth of the hole in the chuck. The core box is shown in Fig. 200.

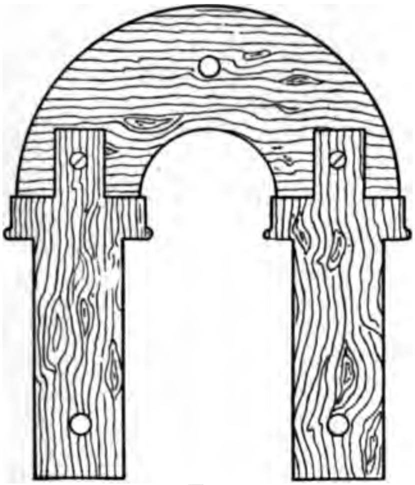


Fig. 197.

When pipes or cylinders are of moderate size with deep flanges for bolting together (Fig. 201), the flanges for the pattern are turned out of a separate disc as shown in Fig. 202, and firmly glued and nailed on over the core prints and against the ends of the main body of the pattern; the core print being made of sufficient length to receive the flange. A recess is sometimes turned in the inside end of the core print to receive the inner edge of the flange as shown in Fig. 203, and into which it is fitted, thus adding greatly to the strength of the joint.

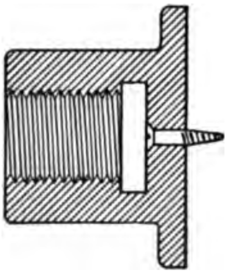


Fig. 198.

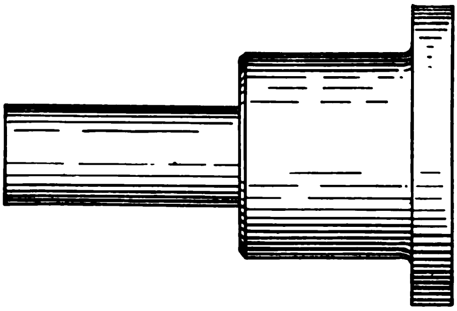


Fig. 199.

The flanges should be made by gluing up *three* pieces and crossing the grain of the pieces so that the grain of each will run at right angles to that of the other. In gluing pieces together for thin discs, *three* pieces should always be used. *Two* thin pieces glued together will always warp.

A still better and stronger method of making large flanges is to cut out segments, five or six for each course, and fit and glue up on a chuck and face-plate in the same way as described for the hand wheel rim (Fig. 168); two or three courses being used for each flange, which after being turned to the required size and form, the ring is sawed in two with a very thin saw, and each half fitted into place on the pattern. The main body of the pattern is glued up out of strips as shown at *a*, Fig. 204, and for turning, the two halves are held together by means of staples as shown in Fig. 188.

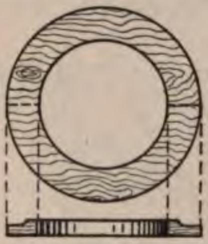


Fig. 202.

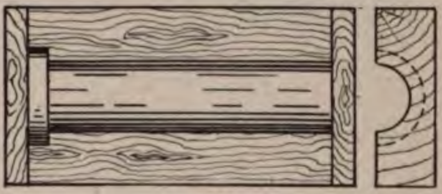


Fig. 200.

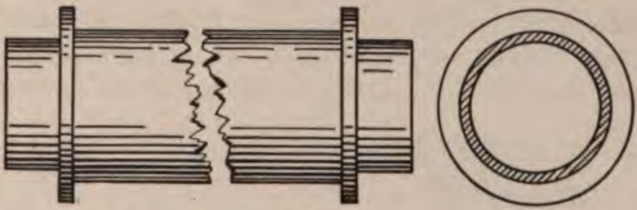


Fig. 201.

A short temporary block is then fitted and glued into the opening in each end to receive the lathe centers. A staple plate, similar to that illustrated in Fig. 205, may be used to great advantage for all work of this kind, making as it does, a secure connec-

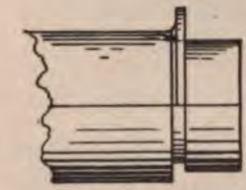


Fig. 103.

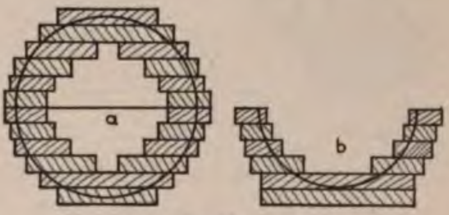


Fig. 204.

tion and doing away with the otherwise temporary center block.

The method of constructing the core box for this or similar patterns, is shown at *b*, Fig. 204.

Tees, elbows, and other bends and connections, when large, are built up in a similar way, thus making a lighter, and also more durable pattern.

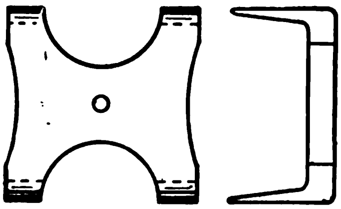


Fig. 205.

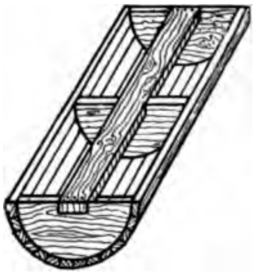


Fig. 206.

For large cylinders, a much lighter and simpler method of constructing the pattern is shown in Fig. 206. For each half of the pattern the two end discs, and the middle semicircular disc are connected together by a strong center bar, which is fitted, glued and screwed into each, serving not only to strengthen the pattern, but also to hold the connecting dowel pins. When the two halves of the pattern are clamped together (with staples) it serves also as a secure means of centering in the lathe.

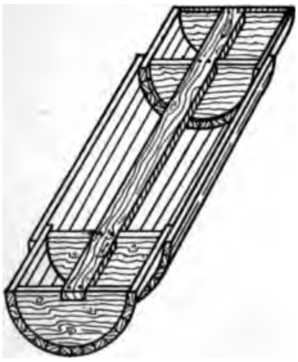


Fig. 207.

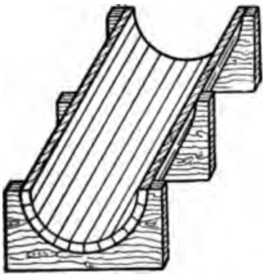
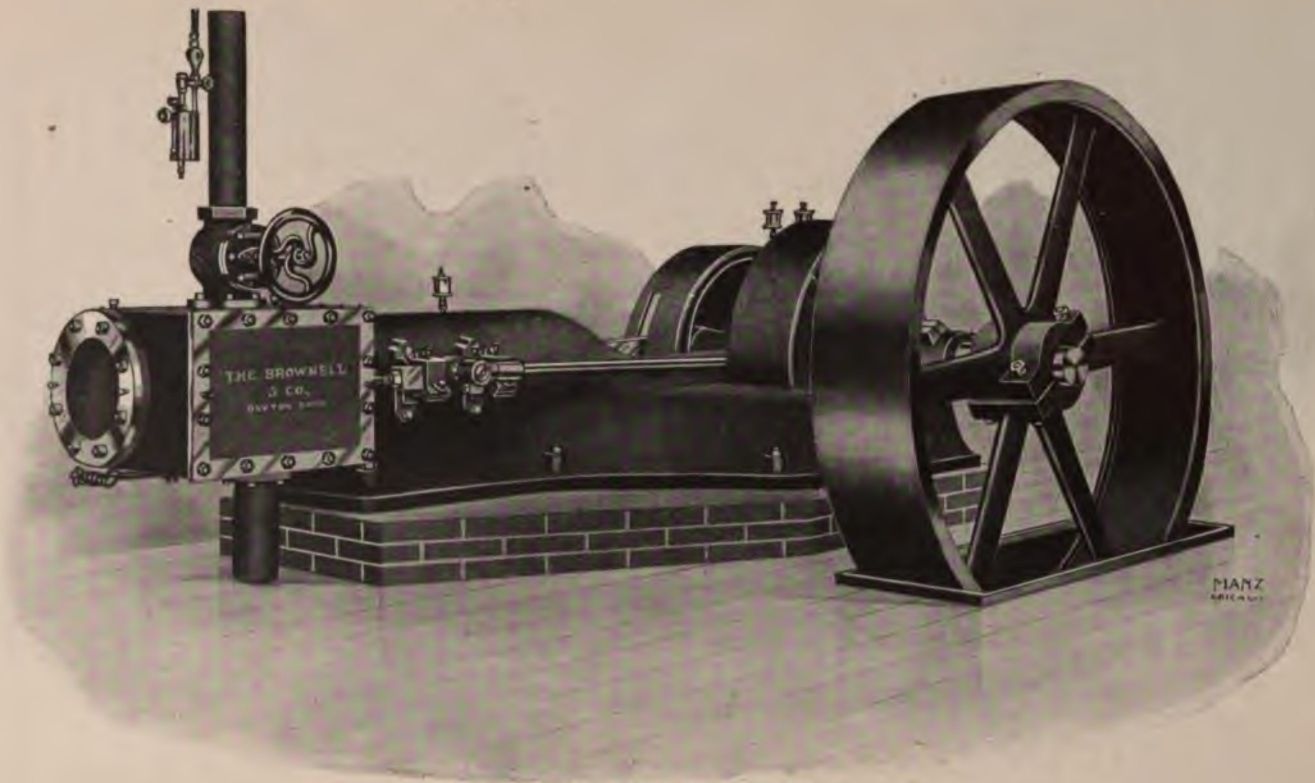


Fig. 208.

The staves forming the body of the cylinder are fitted and glued to each other and screwed, or nailed to the discs. After the



SELF-CONTAINED AUTOMATIC ENGINE.
The Brownell Company.

cylinder has been turned, the core prints and flanges are built up and turned separately, and glued and screwed to the ends of the cylinder from the inside of the end discs.

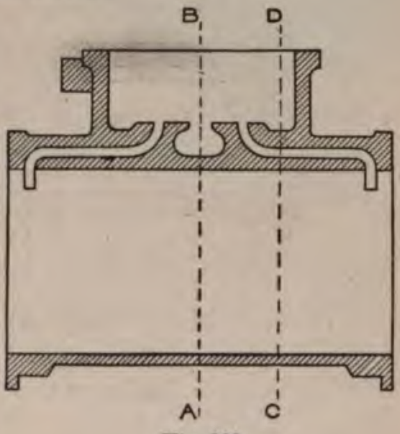


Fig. 209.

Fig. 207 illustrates still another and better method of building up the cylinder and core prints in one piece and completing the whole at a single turning. The core prints, as shown, are staved up first, and then the staves to form the body of the pattern are fitted, glued and screwed, or nailed, over the ends of those which form the core prints. Should the body of the cylinder be long, one, two, or more middle semicircular discs must be used.

A similar construction for the core box is shown in Fig. 208, and is to be preferred to all others because if laid out and built to the exact size, the labor required to reduce the staves to a perfect semicircle of the required radius is very little.

ENGINE CYLINDER.

The slide-valve engine is built in a great variety of forms. Fig. 209 represents a sectional view of the cylinder of a very common type. At *e* Fig. 210, we have a cross-section through the steam chest and exhaust port at *A B;* and at F, a cross section at *C D* through the steam port.

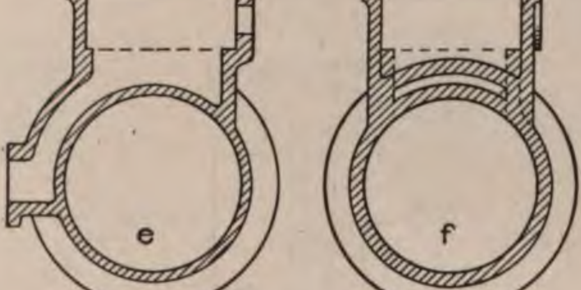


Fig. 210.

When the cylinder is small (ten inches or under in diameter) the pattern is usually built up solid, but if more than ten or twelve inches in diameter it should be built of staves, as shown in Fig. 211.

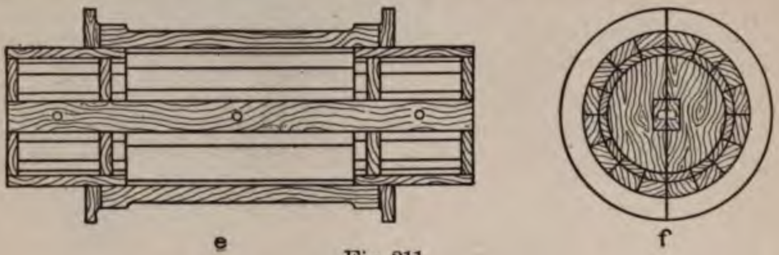


Fig. 211.

When the size is thirty inches or over, a loam mould is usually made as will be fully described in the section on Foundry Work. The size limit, however, varies greatly in different foundries.

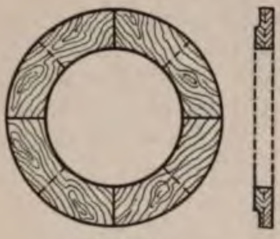


Fig. 212.

The construction of the pattern is illustrated in Fig. 211, and needs no description here, it being the same as already given for Fig. 207. The flanges, however, should be built up of segments of two or three layers each as shown in Fig. 212. After gluing up to the necessary thickness to make the flange, it is sawed in two halves, jointed and carefully centered on a wooden chuck and turned to the dimensions required.

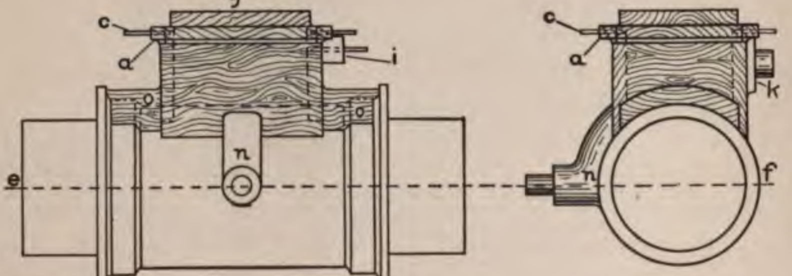


Fig. 213.

The centering must be done with accuracy, or one half of the flange ring will be larger than the other. The steam chest is next built and fitted centrally on the upper half of the cylinder pattern as in Fig. 213. The projections *a*, *a*, which give the extra width of metal for the bolts of the chest cover are left loose, being kept in place by long wires or dowel pins as shown at *c*, *c*, so that they can be withdrawn separately from the mould after the main part of the pattern has been taken from the sand. These four strips should be recessed into the corners of the chest one quarter inch, as shown by the dotted lines, to prevent them from being rammed out of place after the dowel pins are taken out. The boss *i* for the valve-rod stuffing box, and also the boss *k* around the steam-pipe opening, must be loose so as to be taken out of the mould after the pattern has been removed.

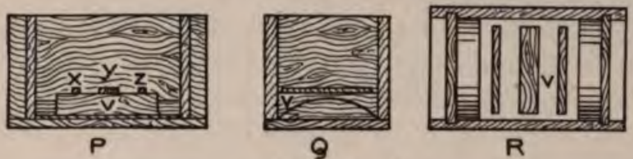


Fig. 214.

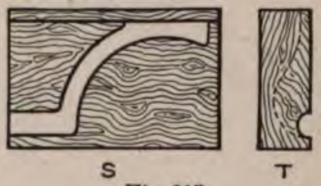


Fig. 215.

The pieces *o*, *o*, at each end of the steam chest, which form a thickness of metal over the steam ports, are next fitted in place, as also the exhaust passage *n* which must be parted on the line of parting of the two halves of the cylinder pattern.

The main core box for the cylinder is made in the same way as has been already described for Fig. 208. The steam-chest core box is shown in Fig. 214, in which P is a side view, one side of the box being removed to show the valve seat *v*, and the core prints *x*, *z*, and *y*, which form recesses in the core, into which the upper ends of the two steam inlet cores, and the central exhaust passage core are placed. Q is an end view of the box with one end removed, and R is a view looking into the box from above.

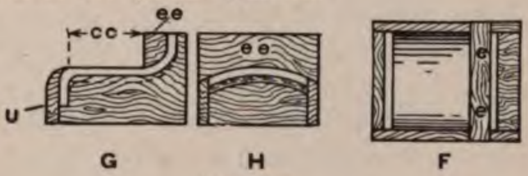


Fig. 216.

For the core forming the exhaust passage, two half core boxes, one right and one left, will be necessary. One half of this box is illustrated at S. Fig. 215, as also a sectional view at T. The dotted lines show the manner in which the passage is widened to retain the full size of the opening throughout.

Only one core box will be needed for the two steam ports. Three views of the box are given in Fig. 216. At G one side is removed, giving a side view of the construction of the box. H shows a cross section through G with the end *u* removed, and F is a view from above. The core is swept off on the upper side for the length of *c c*, and the bar *e e* as well as the end *u* must be movable so that the core can be taken from the box. Both ends of the core change from circular into straight parts just at the entering of the cylinder, and at the entering of the steam chest.

The entire set of patterns are simple and easy of construction, if carefully made drawings are furnished to work from; the time and labor required, depending entirely upon the size of the cylinder.

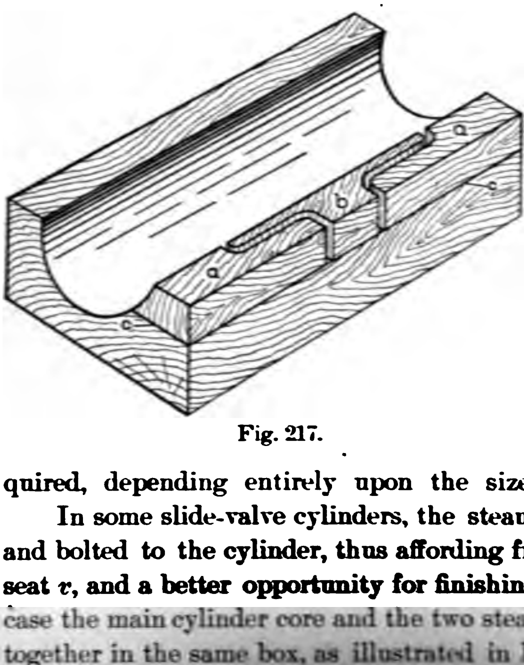
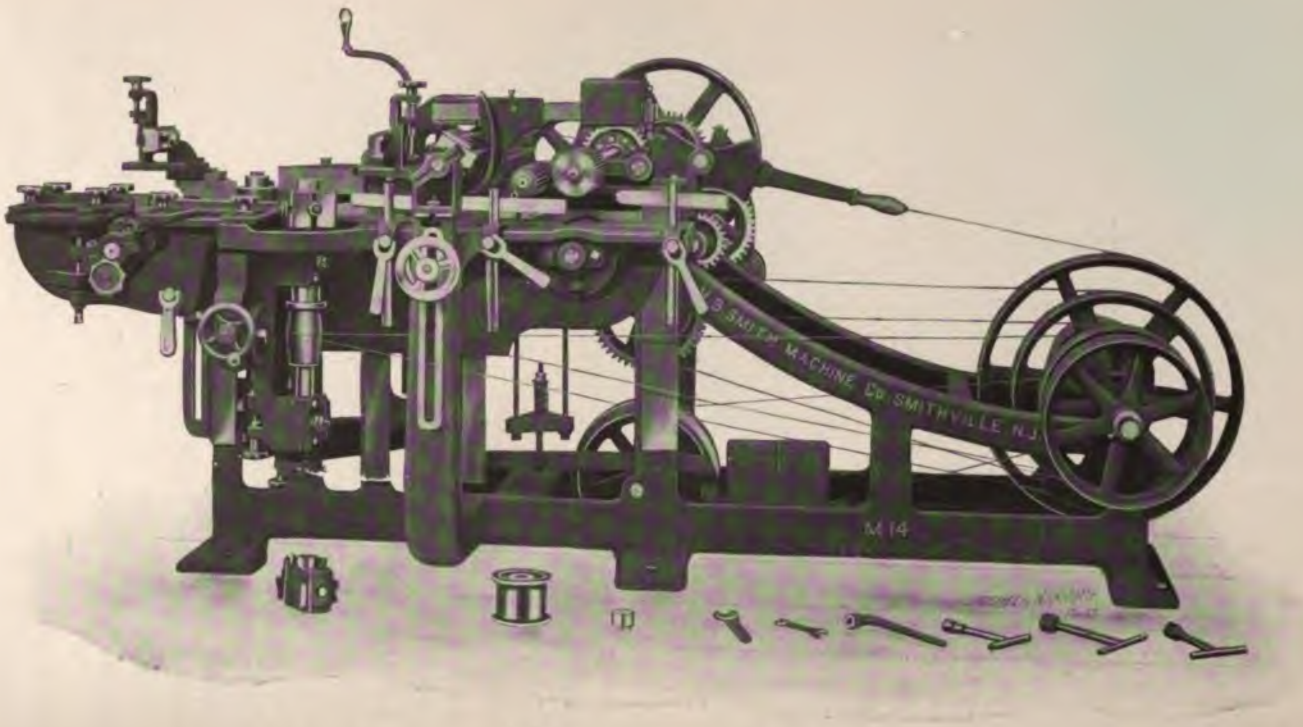


Fig. 217.

In some slide-valve cylinders, the steam chest is cast separate and bolted to the cylinder, thus affording free access to the valve seat *v*, and a better opportunity for finishing and fitting. In this case the main cylinder core and the two steam inlet cores are made together in the same box, as illustrated in Fig. 217, in which one side of the core box is cut away to a depth of one half of the length of the steam port openings, or to the line *c*, *c*, which must be just one half of the inside width of the box as shown at *H* and at F, Fig. 216.

The part which has been cut away is replaced by the three blocks *a*, *a* and *b* [illegible] give the required size and form to the [illegible]



6-INCH MOULDING MACHINE.
H. B. Smith Machine Co.

These blocks are fastened by dowels, loosely, to the main part of the core box, and after the core has been rammed up, the whole box and core is turned over on its face and the main part of the box is lifted off, after which the two loose blocks *a* and *a* can be drawn away endwise and the block *b* can also be lifted out with ease.

GLOBE VALVE.

The globe valve, shown in section in Fig. 218, is a good illustration of a pattern in which, while the outside may be very simple, the inside is intricate and requires considerable practice and skill to so contruct the core boxes that the core can be withdrawn from them, and at the same time give uniform thickness and strength to all parts of the shell and to the internal partitions.

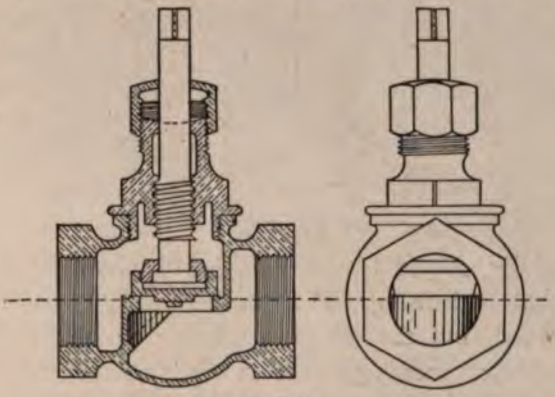


Fig. 218.

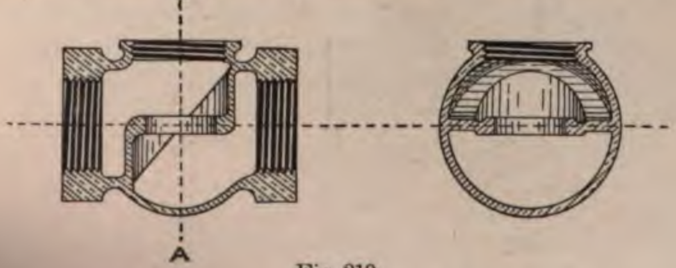


Fig. 219.

In Fig. 219 is shown a sectional view of the body of the valve, [illegible] 0 an illustration of the completed pattern, from [illegible] n that almost the entire work, with the exception ng the dowel pins, and forming the two hexagonal in the lathe. The construction is shown in the tion of the half-pattern, Fig. 221. The wood for must be of sufficient length to allow for gluing at r the insertion of iron staples. In turning, the ust be taken to center exactly on the parting line of s.

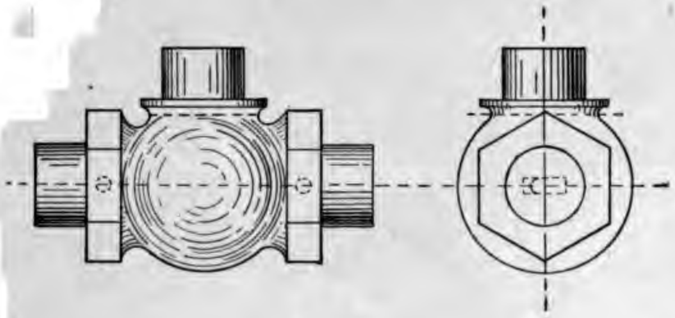


Fig. 220.

arefully shaped template, such as is shown at *a*, Fig. 221. used in turning. This template may be made of a thin wood, but for all purposes for which templates are . in pattern making, and their use is necessarily very great, sheet zinc is the best material. It is soft, and easily cut and filed, and does not dull the cutting tools so much as other metals

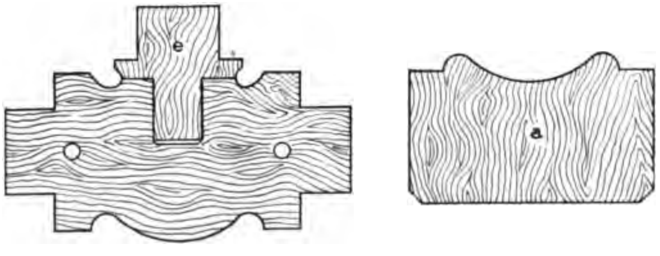


Fig. 221.

Before marking out the template, that the lines may be more readily seen, it should be cleaned with a piece of emery cloth and have a dark coating of the following solution. Dissolve an ounce of sulphate of copper in about four ounces of water and to this add one teaspoonful of nitric acid. Treat the surface of the zinc with this solution, rubbing on with a piece of waste. A thin coating of copper will thus be given to the zinc (also to steel or iron). When applied to finished surfaces they should be rubbed dry, as iron or steel will be rusted.

When the curves of the template will allow of sawing, the zinc template is easily shaped by placing a piece of zinc of the necessary size between two boards, and nailing them together. The required shape having been drawn on the upper board, the whole may be sawed to the form required on the band saw or scroll saw, but preferably on the latter, with a fine tooth narrow saw blade which will give a smoother edge to the zinc. If the boards are firm, the metal will offer no resistance whatever to the saw, nor will the saw be perceptibly dulled. For small curves, lay the zinc on a piece of hard board, and with a pair of sharp pointed dividers the zinc can be scratched half way through its thickness, then by turning it over and placing the dividers in the same center, the other side may be cut in the same way, or so nearly through that it will break off. This affords a truer and more uniform curve than can be obtained in any other way. The legs of the dividers must be stiff and firm so as to be entirely free from vibration. After cutting, the sharp edges of the zinc may be dressed with a fine double-cut file, or better with fine emery cloth or sand paper rolled over a wooden holder.

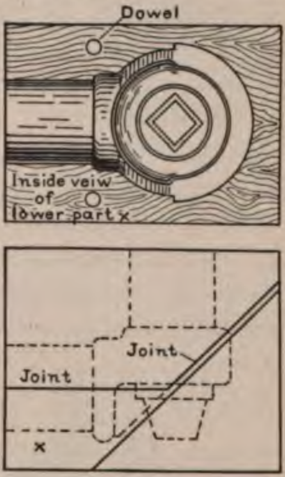


Fig. 222.

The lathe should always be stopped when testing the work with the template, and great care must be taken to make the two ends of the pattern symmetrical.

When the turning is nearly completed the template itself may be tested by reversing the ends. If not true it should be filed to the proper shape as shown by the drawing.

The branch *e* must be turned in the same way as described for the main part of the pattern which is pared off, or planed off in a large pattern, to the exact size of the base of the branch, and when the pattern is large and heavy, one or two wood screws should be used in the tenon of the branch to assist in keeping it in place.

In all small and moderate-sized valves, the flanges are hexagonal in shape as shown in Figs. 219 and 220. The core for a globe valve is made in two parts, and the core box for each part must be made in upper and lower half, making four parts to the core box. This is necessary in order to allow for the removal of the core from the boxes. The internal shape of the boxes are difficult to illustrate on paper, but if the drawings given in Figs. 222 and 223 are carefully studied in connection with the sectional views of the valve shown in Fig. 219 their shape and construction should be readily understood.

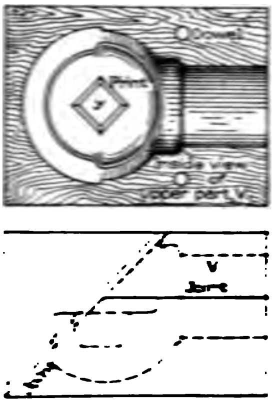


Fig. 223

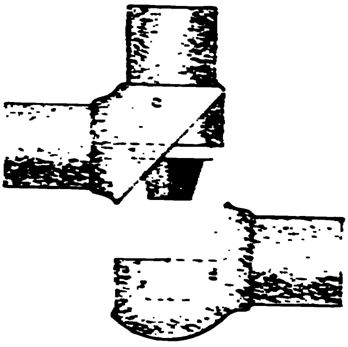


Fig. 224

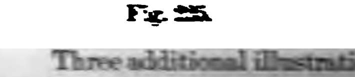


Fig. 225

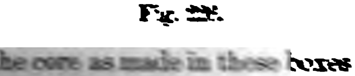


Fig. 226.

Three additional illustrations of the core as made in these boxes are shown in Figs. 224, 225 and 226.

In Fig. 222 there are two views of the box in which the upper part C of the core shown in Fig. 224 is made. This box separates along the two lines marked "Joint" (Fig. 222) and, as will be readily seen, allows the core to be easily removed when the box is opened. The lower part *d*, Fig. 224, of the core is made in the box shown in Fig. 223. The part *c* has a square tenon which fits into the mortise in the part *d*. This mortise is made in the core by means of the print marked Y in Fig. 223, and as will be seen by Fig. 224, this core tenon and mortise will bring the two parts of the core into perfect alignment when they are pasted together.

In Fig. 225, we have an outside view of the completed core and in Fig. 226 a sectional view through the middle of the core, lengthwise; from which the necessity for the tenon and mortise connection will be readily understood, this being the only connection between the two parts of the core. In working out the core boxes it is well to use templates which can be formed and made from the drawings furnished. The templates will aid in getting the proper shapes, and leaving a uniform amount of metal in all parts of the case.

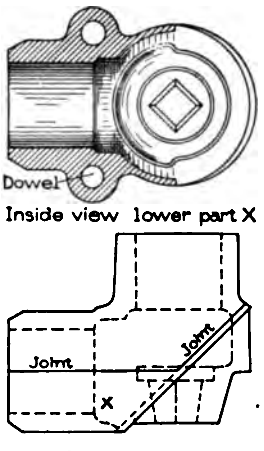


Fig. 227.

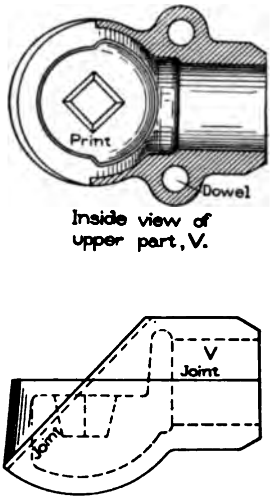


Fig. 228.

Figs. 222 and 223 illustrate the common wooden core box, but to insure uniformity, and because of the necessary wear and fragile character of wood for boxes of this kind, these core boxes should be made of metal. The wooden pattern for the metal core-box must then have an allowance for double shrinkage, and to xcessive weight, the box is made in the form shown in Figs. and 228. In this form all unnecessary metal is removed and connecting iron dowel pins are placed in lugs or thin outside ections as indicated.

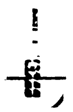


Fig. 229.

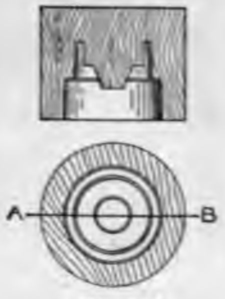


Fig. 230.

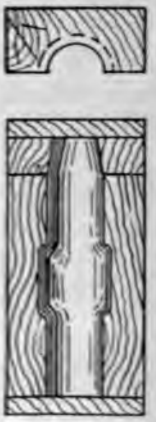


Fig. 231.

Fig. 229 illustrates the pattern for the stuffing box and bonnet he valve, with core print turned on each end, which, like the main attern of the valve must be parted, or made in two halves. Two core boxes are necessary to make the core for this part of the valve.

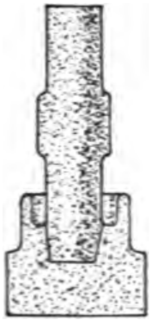


Fig. 232.

From Fig. 230 it will be seen that the core box for the lower end of the core can be turned out on the lathe by using a template of the required shape. For the upper part or stem, the half box shown in Fig. 231, is all that is necessary. By examining the two core boxes, Figs. 230 and 231, it will be seen that here again we have recourse to the tenon and socket form of construction for uniting the two parts of the core which are shown pasted together in the completed core, Fig. 232. The nut for the bonnet is shown in Fig. 233, and the pattern, which is hexagonal, should be so made as to form its own core, as indicated by the dotted lines in the drawing. Fig. 234 shows the pattern for the valve and also the pattern for the valve nut, each of which will form its own core, and Fig. 235 is an illustration of the pattern for the valve spindle.

GEAR WHEEL PATTERNS.

In this special class of pattern work, the greatest accuracy and care must be taken, not only in building up the rim of the wheel, but in fitting and placing on the rim the blocks, out of which the teeth are to be formed, and most of all in laying out the teeth regularly and, accurately on the tooth blocks. A pattern for a gear wheel, whose teeth are carelessly made is almost worthless, the time lost in chipping and filing, for the purpose of correction, being too great to allow the use of such a pattern.

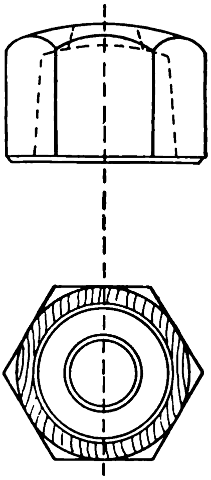


Fig. 233.

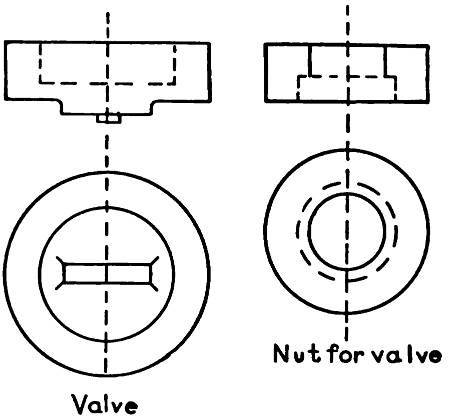


Fig. 234.

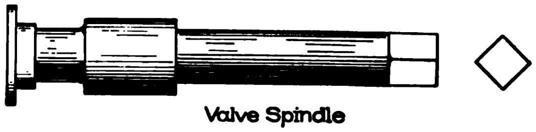


Fig. 235.

To insure greater accuracy and smoother running gears, it is now the custom in many shops to have the wooden pattern made in the form of a blank, (without teeth) from which a metal pattern is cast.

This cast pattern is turned up and placed in the milling machine where the teeth are cut and spaced with accuracy and to the exact form of tooth required. This metal pattern is used without *draft*.

This method of making gear patterns, however, is expensive, and is used only when many wheels are to be cast of the same size and number of teeth from the same pattern, and, as in the case of pulleys, the wooden pattern is still used for all special sizes of gears.

For these wooden patterns we shall now give a few hints as to the best methods of construction. As the form of the tooth used by the draftsman will play no part in the construction of the pattern, we think it would be out of place here to enter into a discussion of the relative merits of the single curve, double curve, or other form of tooth.

The single curve or involute tooth, however, has the great advantage of being the only form of gear which can be run at varying distances of axes, and transmit an unvarying velocity and amount of power. The common contention that two gears will crowd harder on their bearings when the single curve, or involute form is used, has not been proven in actual practice. The practical methods for obtaining the curves for either the involute or for the epicycloidal tooth, the two forms in most common use, are taken up in Mechanical Drawing.

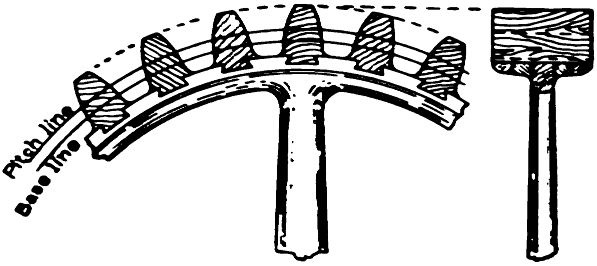


Fig. 236.

In the illustrations here given the single curve form of tooth is used.

In the construction of gear-wheel patterns, the methods employed in making and fastening the tooth, or the blocks out of which the teeth are to be formed, to the rim of the wheel, varies greatly. It was formerly the custom to dovetail the tooth into the rim of the wheel as shown in Fig. 236. This was the case especially when the teeth were large, as in 2 pitch or larger.

This is, however, an unnecessary expense and a waste of time, and in addition, the cutting of the dovetails and the driving home of the dovetailed tooth, often have the effect of distorting the rim to some extent. A better, or at least a more economical method is to fit the tooth blocks as shown in Fig. 237, which for strength and durability is found to be in no way inferior to dovetailing, and the saving of labor and time is very great.

In this method we have always the advantage of a smooth, clean fillet at the root of each tooth, and having the grain of the wood, not only for the fillets, but also on the whole depth circle, run in the same direction as the grain of the wood which forms the tooth. This means a smoother pattern, more easily moulded, and a better casting.

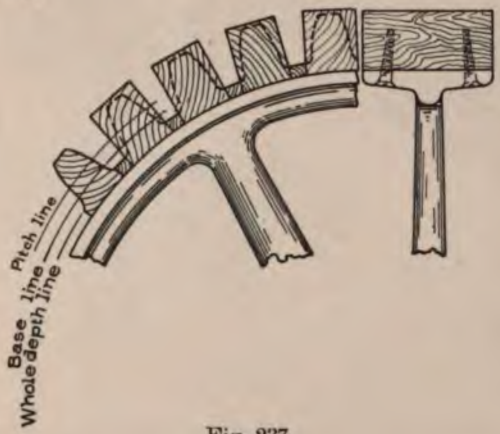


Fig. 237.

In the former method, Fig. 236, it is almost impossible to form a fillet on each side of the tooth, as it runs off to a thin feather edge which continually splinters and chips off; still further, the bottom of the tooth space, that is, the whole depth circle is the rim of the wheel, composed of layers of segments with changing grain which will not mould so smoothly as in the second method.

The blocks for the teeth should always be cut in strips two or three feet in length, in order to thoroughly season the wood, at least so far as it is possible to do so, while other parts of the wheel are being constructed.

Only straight-grained wood should be used for teeth. The segments for building up the rim should be cut out next, then the arms put together and shaped as required. It is a good plan to fasten the arms central to the face plate of the lathe, and to turn out a recess, say $\frac{1}{16}$ inch or $\frac{3}{32}$ inch deep to receive the hubs as shown in Fig. 238. This makes a stronger connection and does away with the trouble of fitting and connecting the hub, with the thin feather edge of the hub fillet, to the surface of the web of the

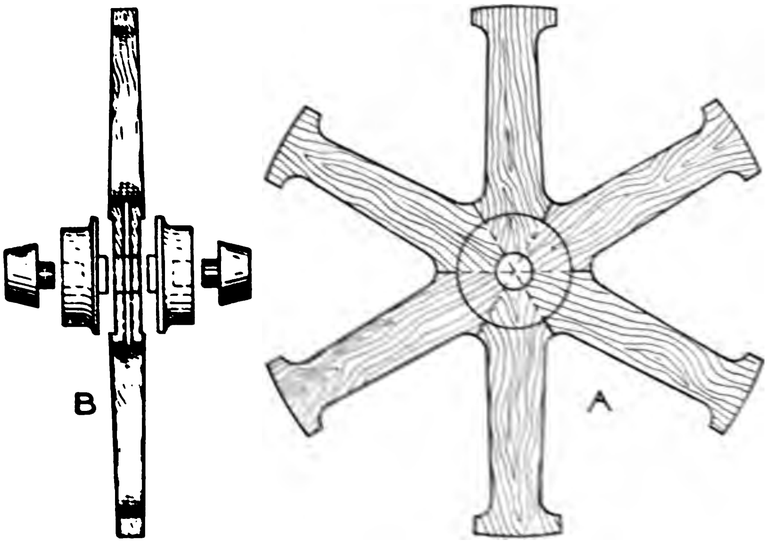


Fig. 238.

arms. The same method is of great advantage when fitting the hubs of pulleys and other wheels. The arms must be put together, with inserted tongues in the joints, as illustrated and described in Fig. 169; and if they are to be worked to an elliptical section, it is easier to do this before fixing them in the wheel. At A, Fig. 238, the construction of the arms is shown, and at B the core prints, hubs and arms, with the manner of connecting them [illegible]

After building up enough courses of [illegible] the width of the rim plus half the thi[illegible] only of this part of the rim is tu[illegible] including the central [illegible] just equal to the th[illegible] receive these ends are now cut into this half rim, and the arms fitted and glued in place but not so tightly as to strain the rim and cause it to spring after it is removed from the chuck. The remaining courses for the rim are now fitted and glued on, and the rim turned and finished to the required size and shape.

The face should be glue-sized to prepare it for the blocks which are to form the teeth of the gear.

After sizing and removing the raised grain of the wood, the periphery of the wheel must be spaced for the required number of teeth. With a try square and very sharp awl draw lines through the points obtained by the spacing as shown in Fig. 240. Should the teeth be of moderate size, say 3 pitch or less, the tooth blocks should be glued on so as to meet each other on the rim of the wheel as shown in Fig. 241.

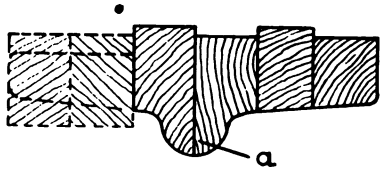


Fig. 239.

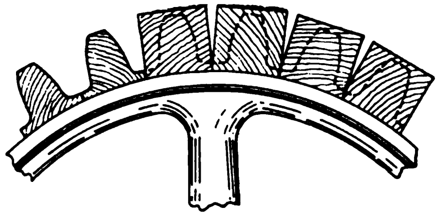


Fig. 241.

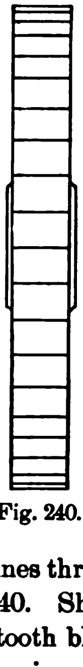


Fig. 240.

Each block must be so fitted as to reach only from line to line, Fig. 240, care being taken to have each block parallel to, and coincide with its own line, *reaching exactly to the line.* When all the blocks are placed and glued, the wheel is returned to the lathe and the periphery turned off straight and to the required neter for the addendum, or extreme ends of the teeth. The of the blocks are also turned even with the edge of the wheel rim, and before removing from the lathe, a circular line must be drawn on the ends of the blocks, on both sides of the rim, indicating the whole depth of the teeth. The use of this line will be explained later; it is the only circular line needed for laying out, or for working out the teeth. When the teeth are large, a tooth block is first fitted on and screwed from the inside of the rim as shown in Fig. 237, one edge of the block touching, but not covering its line on the face of the rim. The thin strip is next fitted, glued and braded against the block with the opposite edge of the strip reaching just to, but not covering the next line. A second tooth block is fitted and screwed in place, then a second strip, and this alternate placing of blocks and strips continued until the surface of the rim is covered, having a block and strip for each tooth required.

Care must be taken not to allow any glue to get between the blocks and the strips when gluing and nailing the strips on, as each block must be taken off, one at a time, after being laid out, to work the tooth to shape. When all the blocks and strips are in place, the wheel must be returned to the lathe and the face of the blocks turned to the diameter required for the addendum or outer ends of the teeth, and the ends of the blocks also turned even with the rim.

The whole depth circles are marked, one on each side, while revolving in the lathe, as explained for a wheel with smaller teeth. All parts of the rim should now be made perfectly smooth with fine sand paper using a holder or block, to prevent rounding the corners or angles of the tooth blocks.

Beginning at the middle of a block, space the required number of teeth on the periphery of the tooth blocks, and should the first trial not result in even spaces, the trial spacing must be continued until the greatest accuracy has been obtained, that is, until all distances from point to point are exactly equal. Through each spacing point, found as above, very sharp but light lines are drawn across the face of the blocks, as was shown for the wheel rim in Fig. 240. When drawing these lines it will be found best to draw along the *inside* edge of the try square blade instead of the outside as is usual. The reason for this is that on small or medium sized wheels, a much firmer base will be given for holding the square, and more accurate lines will be the result. A coat of shellac brushed over the ends and faces of the blocks, if sand-papered smooth after being allowed to dry, will greatly assist in laying out the teeth, hardening the surface, and enabling sharper lines to be drawn. A template must next be made of the exact form of the tooth required. This will always be given full size in the detail drawings furnished to the pattern maker.

Should the wheel be of small diameter the template may be laid out and cut on the end of a long strip of zinc, but it is better to fasten the template to the end of a wooden bar, as shown in Fig. 242 a narrow slot having been cut through the back end of the zinc to allow of exact adjustment to the diameter of the wheel.

This wooden bar is hung centrally on a peg or dowel which must be placed exactly in the center of the hub. For this purpose it is customary to use a block of wood as a temporary hub, the center of which may be easily found from the periphery of the blocks by the dividers. A very slight, sharp notch is made in the exact center of the end of the tooth template, which must be radial to the hole in the opposite end of the bar on which the template revolves. This notch is shown in Fig. 242.

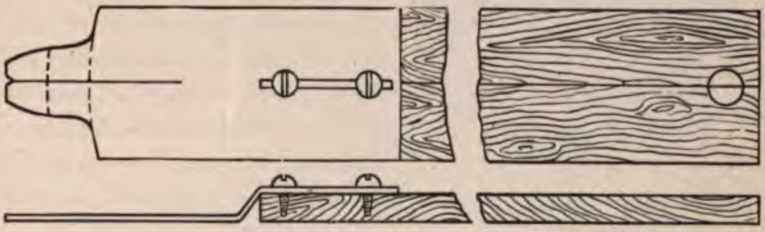


Fig. 242.

To use the template, place it over the center pin and bring the notch exactly in line with one of the spacing lines on the outside of a block and with a very sharp pointed awl mark the tooth on the end of the block. Then swing the template to the next line and mark as before, continuing the process until a tooth has been laid out on the end of each block. The wheel is now turned over and the same process repeated on the other side. It will be readily seen that if the spacing lines have been squared across the face of the wheel with accuracy, the teeth laid out on the two sides will be true and perpendicular to each other, a spacing line forming the exact center of each tooth, and for this reason these lines should always be very light but sharp and clearly defined.

For convenience in cutting and paring, a second series of lines should now be drawn across the face of each block connecting the extreme ends of the lines which describe the shape of the tooth on each end of the block. Should the wheel be small and within the capacity of the band saw, all superfluous wood may easily be removed from between the teeth.

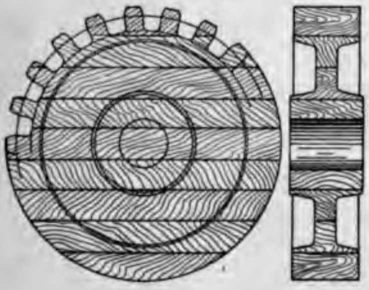


Fig. 243.

If the band saw is sharp and evenly set, and the operator skillful, the teeth may be sawed so as to need but very slight correction with the paring chisel and gouge.

As the hubs usually project beyond the rim on each side of the wheel, they should be left loose and removed before placing the wheel on the saw table.

For large wheels and heavier teeth, each tooth block should be unscrewed and removed, one at a time, and planed to the lines marked on its ends and face, after which it is returned to its place before a second one is taken off. This is continued until all the teeth are shaped, when it will be necessary only to construct fillets at the base of the teeth, and also to work each space down to the *whole depth circle*, the circle having been drawn for this purpose, and also as a guide, for bringing all tooth spaces to the same depth.

Small gears, or pinions as they are called, are usually made with a solid web instead of arms, and are glued up in solid blocks of end wood, the grain of the entire block running parallel with the face of the teeth. Such an end wood pinion is shown in Fig. 243. It is turned and the gear laid out and cut in the same way as described for the larger wheels, except that the teeth are not glued on but cut out in the solid disc. In the construction shown in Fig. 241, the teeth, not being screwed on, must be nailed with brads, *after* being shaped and finished, from the face of each tooth into the rim.

Patterns for Bevel Gears are built up as illustrated at *a*, Fig. 244, the wooden face-plate, or chuck, being provided with ten or more radial blocks as shown and described in Fig. 168. The advantage of the blocks is that they keep the first layer of segments out from the face-plate and give easier access to the back edge or angle of the rim while being turned.

The segments are usually made to overlap as shown, which is not only a saving of wood but also saves the time which would be required to turn the angular rim from a square construction. When a sufficient number of courses have been built up, the face and two edges are turned to the required angles, as indicated by the dotted lines in *a*, Fig. 244. The rib *c* which will finally be a continuation of the arms, is also turned to shape and to the thickness of the ends of the arms. The rim will then present the appearance shown at *b*, Fig. 244, except the arms which are here shown in place.

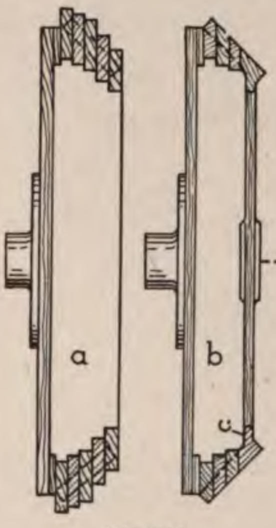


Fig. 244.

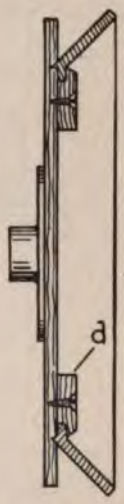


Fig. 245.

The rim is next cut from the blocks, and an angular groove turned in the face of the chuck which will fit and center the finished edge of the rim on the faceplate. In this position the inside of the rim is turned and finished as shown in Fig. 245. The rim is retained on the chuck by four or six cleats, *d*, Fig. 245, the cleats fitting over the rib *c*, Fig. 244, and preventing the rim from moving and changing its position on the chuck.

It is not necessary here to describe the method used in finding the required angles for the face and edges of the rim, but as in the case of spur-gear teeth, the student should refer to Mechanical

Drawing. The arms, partly shown in Fig. 246, in place in Fig. 244, are next fitted and fastened to the rim. It is well to glue a small disc on each side of the web of the arms as shown in Fig. 246, which not only strengthens the arms, but serves as a fillet around the hub of the wheel.

The blocks for the teeth are next fitted in place, either as illustrated in Fig. 247, or in the form of alternate blocks and strips as was shown for the spur gear, Fig. 237. After all the blocks are in place, the wheel must be put in the lathe and turned to the sizes and angles required for laying out the teeth. A sharp line must be drawn on the face of the blocks, while in the lathe, to serve as a guide for the dividers while spacing the teeth.

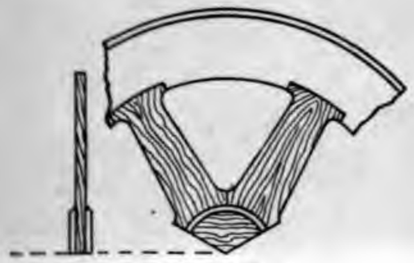


Fig. 246.

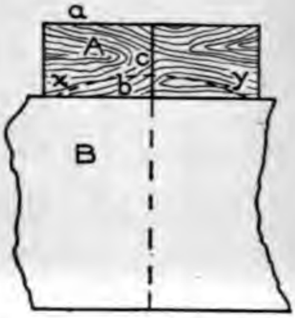
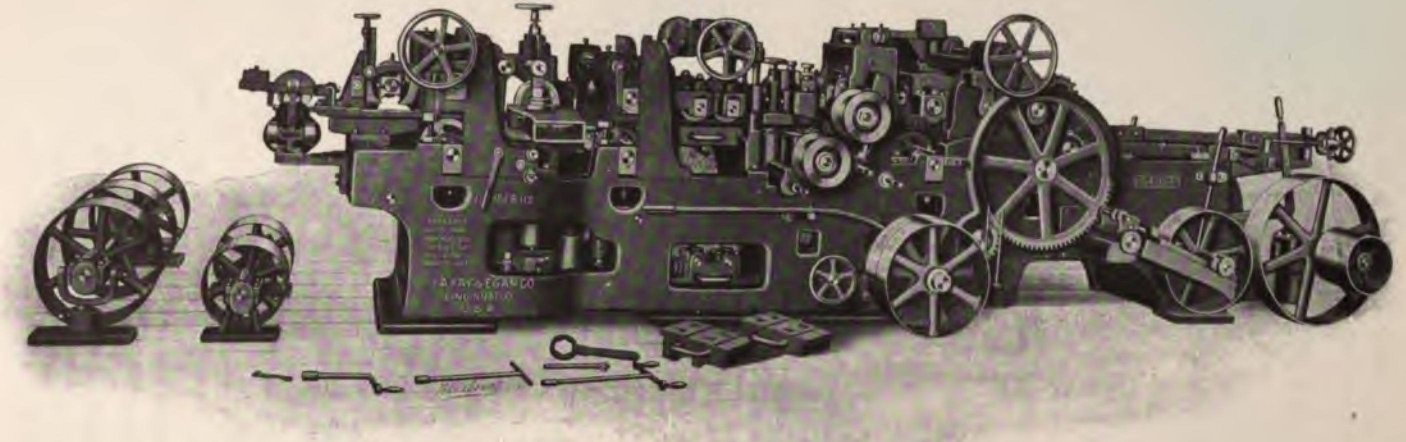


Fig. 248.

To obtain the center lines for the tooth faces after spacing on the blocks, it will be readily seen that the ordinary try square cannot be used as in the case of the spur gears. A temporary square must be made for this purpose as follows:

Take a piece of hard wood, about 6 inches long and 3½ inches wide and ½ inch in thickness. Dress the two edges perfectly parallel and from the upper edge *a*, Fig. 248, with a try square and a sharp pointed knife, draw the line *c*, equally distant from each end of A, and at right angles to the edge *a*. Lay the edge *b* of A, against another board B, of the same thickness, and continue the line *c* on this board as shown by the dotted line. With the dividers set to a radius equal to the longest radius of the outside ends of the tooth blocks, from the extended line *c* on the board B, describe the arc, *x y* on A. Cut the edge *b*, to this arc and see



FIXED KNIFE PLANER FOR HARDWOOD FLOORING.

J. A. Fay and Egan Co.

that it fits perfectly the outer rim of the tooth block. Next make a thin blade of hard wood and screw to the head A, using the greatest care to have one edge of the blade coincide exactly with the line *c*. After screwing the blade to the head, its accuracy may be tested by placing a try square against the edge *a*. The result will be as shown in Fig. 249, in which the edge *c* is radial to the arc *x y*. This edge will describe the center lines of the teeth radially as required.

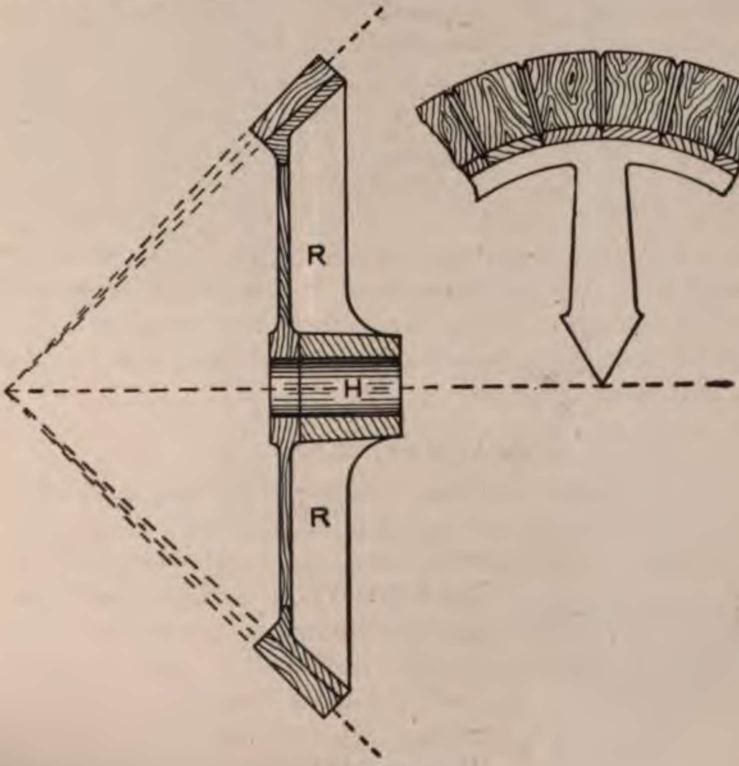


Fig. 247.

This temporary square can be used up to a certain limit, on wheels of larger diameter than that to which it has been fitted, but cannot be used for smaller wheels. For larger gears the position will be as shown in Fig. 250, which will give the correct per- [illegible] at *x* and *y* are carefully made. By using [illegible] res will be needed for a great number of wheels. In Fig. 247 the hub H and the ribs of the arms R R. are often made loose so as to lift with the cope, which is of great advantage in moulding. When the teeth are large, they must be screwed on from the inside of the rim. If small, they should be braded from the outside, or face of the tooth, into the rim *after* the teeth have been shaped and finished. Two templates will be necessary for laying out the ends of the teeth, the outer ends being larger than the inner. These templates are made as described for spur gears, and have the outer end bent to fit over the angles of the rim.

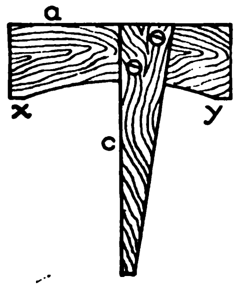


Fig. 249.

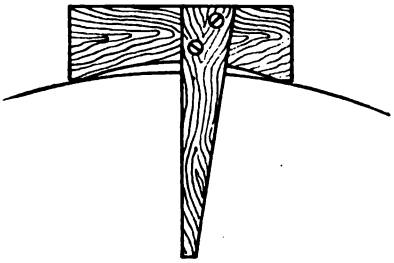


Fig. 250.

COLUMN PATTERNS

Cast-iron columns are often ornamented or fluted as shown in the half section of a fluted column in Fig. 251. In all such cases the body of the pattern is made octagonal as shown by the line A B C D E. The loose pieces forming the flutes are held to the main body by pins that stand at right angles to the line A E. After the sand has been rammed, the body included in the lines A B C D E is lifted out leaving the parts A *a* *b* B, B *b* *c* C, etc., imbedded in the sand. Then one after another these are lifted out.

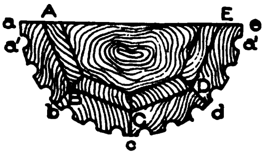


Fig. 251.

These fluted sections should never be so few in number that they cannot be lifted out without tearing the sand. Eight or twelve sections will be needed.

Other forms of ornamentation are put upon columns in a similar manner. Leaves or flowers are held by pins or in grooves in such a way that the main body of the pattern can be lifted out without disturbing them, and they are then withdrawn from the sand through the cavity left by the main pattern.

Cores for Columns. Cores for columns may be made in core boxes as in the case of those for pipe, but where the core is long and straight no core box is needed. The core is usually built of loam about an iron pipe as explained in Foundry Work.

Where the core is to follow the lines of the ornamental mouldings on the outside of the column, it may be provided with a special core box or better with a sweep as shown in Fig. 252. This sweep is used to shape the loam core that is to be built up on an iron pipe. Fig. 252 is the outline of the template that is to be used in sweeping the core for the interior of the columns shown in Fig. 253.

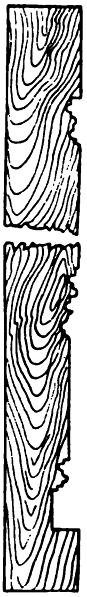


Fig. 252.

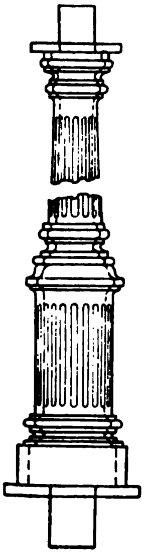


Fig. 253.

Follow Boards. All thin patterns that are likely to suffer distortion from the pressure of the sand while being rammed up, must be provided with accurately fitting follow boards. These follow boards may be made to fit on either one or other of the sides of the pattern.

When the outlines of the pattern are very irregular, the follow boards are often made of plaster or other composition, which, when dry, is used to support the pattern while the drag is being rammed.

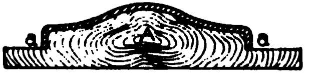
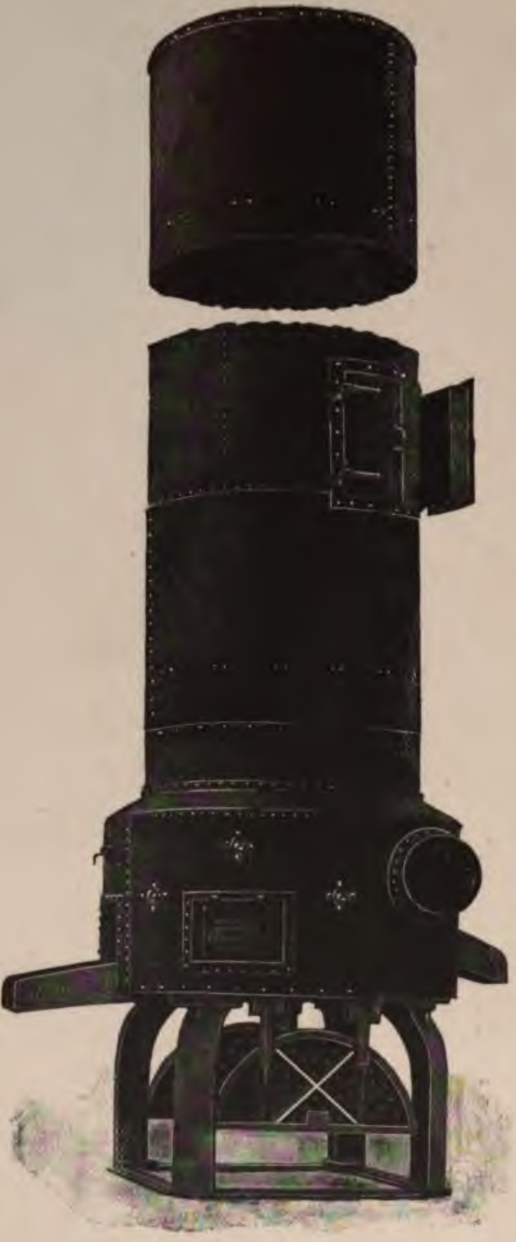


Fig. 254.

Fig. 254 represents a section of a railing cap. If the pattern B were to be set with the edges *a a* resting upon the moulding board and the sand of the drag rammed down upon its upper face, it would be sprung out of shape. To avoid this the follow board A is made to exactly fit the under side of the pattern. Then when the sand is rammed, the whole pattern is supported and there will be no distortion. When the cope is rammed the follow board is removed and the sand of the drag supports the pattern while the cope is being rammed.



THE WHITING CUPOLA.

FOUNDRY WORK.

The art of making iron castings has been brought to its present state of excellence after many years of labor and experiment. Iron in its natural state exists as ores and to be of use to man it must first be smelted to a form that is known as pig iron. In this state it may be puddled or wrought to convert it into wrought iron or steel. Iron, as steel or wrought iron, was known for many centuries before iron castings were made.

There are records of many attempts to make iron castings but there is nothing of importance recorded until 1544 when a patent for making iron castings was granted in England.

The art of making iron castings first became successful about the beginning of the eighteenth century. At this time the primitive cupola was invented. It consisted of a crucible upon which a stack was set. The whole was filled with coal and iron as is done to-day with the cupolas. A blast of air was forced in over the top of the crucible. After it was filled with melted iron the stack was knocked away, the debris cleared, and the melted iron from the crucible poured into the moulds.

About the same time a method of leading off gases from the moulds was discovered at the Darby furnace in Colebrookdale. From this time the art of moulding steadily advanced. The introduction of the steam engine in the last half of the century, materially assisted in the development.

The methods employed in the converting of pig iron come under the subject of Metallurgy. After the pig iron has been run it is remelted in a cupola and then is ready to be made into iron castings. The process of remelting and pouring the melted iron into moulds will be discussed in the following pages.

The Foundry is the name applied to the building, cupola and all the tools and appurtenances that go to form the equipment needed to make iron castings. Of these the cupola is the most important.

The Cupola is the furnace in which the iron is melted. In general construction it resembles the blast furnace in which the pig iron is made. The difference is one of size rather than of principles of construction or operation. There are many patented cupolas but these patents relate, for the most part, to details and do not affect the general construction. The ordinary foundry cupola, as usually built, consists of a shell of wrought iron riveted in the same manner as the shell of a boiler, and lined with firebrick. It is set on end and the bottom is formed of two doors opening downward. A blast of air is admitted above the bottom; fuel and iron are thrown in at the top. Fig. 1 is a vertical section of an ordinary cupola. In this engraving B is the wrought iron shell which contains the firebrick lining and holds the latter in place. The thickness of the plates of the shell varies from $\frac{1}{4}$ to $\frac{1}{2}$ inch according to its diameter. The thickness for one of 45 inches diameter should be $\frac{3}{8}$ inch. This shell and the firebrick lining usually stand upon a strong cast iron base, which in turn is supported by four columns. These are carried on a stone or masonry foundation and are of sufficient length to raise the base three or four feet above the floor.

The lining of the cupola should be made of firebrick. The best method is to use two layers, each 4 inches thick. When the inside layer has burned through it may be renewed without disturbing the one next the shell. Ordinary red brick is sometimes used for the layer next the shell but it is unreliable and used only on account of its cheapness. In lining a cupola the bricks used should be moulded to fit the circle of the shell and should be packed as closely together as possible. The spaces between them should be filled with fire clay but only enough should be used to make an air-tight joint. The smaller the amount of clay used the better. To obtain the best results prepare the clay by making a thin mixture with water. Dip the brick into this mixture before setting, and enough clay will adhere to make the joint. After the brick is put in position rap it sharply with a wooden mallet in order to force all superfluous clay from between the joints. A lining put up in this way will last twice as long as where thick clay is used. The nominal diameter of a cupola is the diameter inside the lining. Hence the inside diameter of the shell should

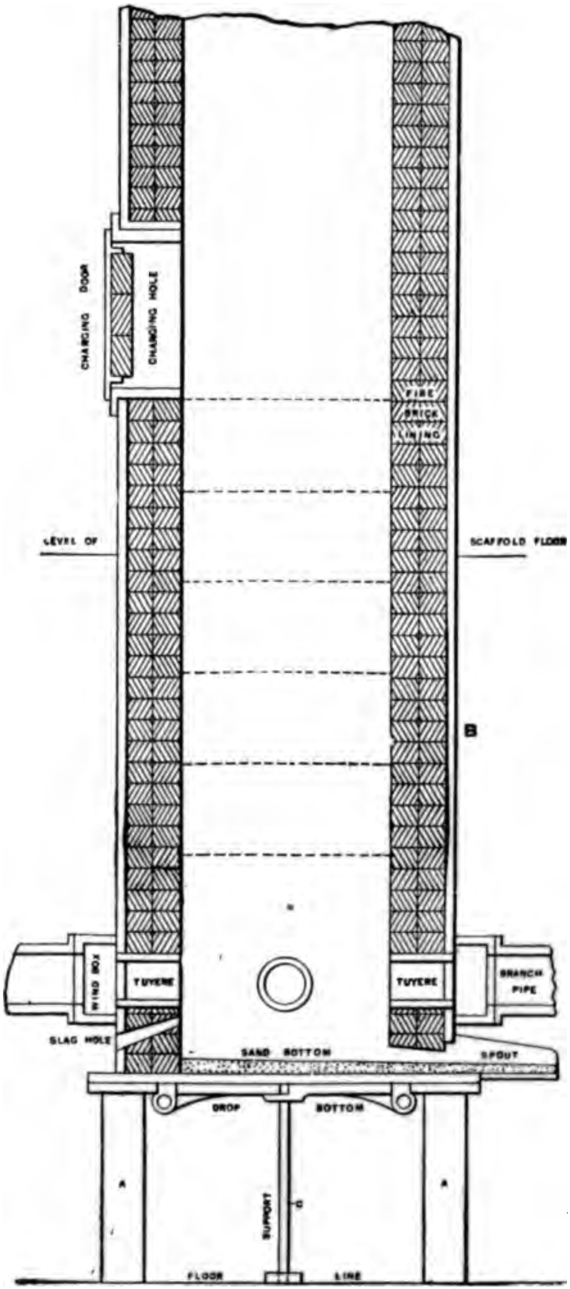


Fig. 1. The Cupola.

be 16 inches larger than the diameter of the cupola. This may be less for very small cupolas. For such six inches of firebrick will be a sufficient thickness of lining.

Sometimes cupolas are so built that the iron and fuel must be thrown in at the top. The ordinary construction, however, is such that the shell and lining are carried high enough to prevent danger of fire from escaping sparks. In this case a charging door is placed in the shell at a convenient height above the bottom. The distance from the base to the bottom of the charging hole is known as the height of the cupola.

The height of the cupola varies with the diameter. For small cupolas the greater the diameter, the greater the height. An approximate formula for determining the height of a small cupola is,

$$H = D \times (6 - \frac{D}{2})$$

in which,

H = the height of the cupola in feet,
D = the diameter of the cupola in feet.

EXAMPLES FOR PRACTICE.

1. What should be the height of a cupola 24 inches in diameter? Ans. 10 feet.

2. What should be the height of a cupola 36 inches in diameter? Ans. 13 feet 6 in.

3. What should be the height of a cupola 72 inches in diameter? Ans. 18 feet.

It may be noted that it is unnecessary to pay any attention to the odd inches in such problems and that the nearest even number of feet may be used. The heights may also be varied from those given to suit various conditions.

The Base of a cupola is usually a square plate of cast iron having a circular hole in the center of the same diameter as the inside of the lining. It is smooth on the upper surface with the exception of a low ring in which the shell is set. The bottom is provided with pockets for the reception of the columns by which it is carried. Lugs are also cast on the lower side to form the hinge connections for the doors. The doors are also of cast iron and are of sufficient strength to carry the load put upon them. One has a lip cast upon it so that a closed surface on the lower side is presented. There is no latch or other means of holding the doors except a prop C which is knocked away when the bottom is to be dumped.

The Windbox is a belt or pipe surrounding the shell a short distance above the bottom. Air from the blower enters the windbox before entering the cupola. The openings from the windbox into the cupola are called *tuyeres*. The location, form and size of the tuyeres have been determined by experiment. They are made square, rectangular, triangular, round and elliptical. Each form has its advantages, although the size and distribution are of more importance than the shape. The distance from the bottom depends upon the work to be done. Low tuyeres have the advantage of effecting some saving in fuel. For ordinary jobbing shops a height of 10 inches from the base to the bottom of the tuyeres will give good results. This applies to all diameters of cupolas. The total area of the tuyeres varies with the size of the cupolas. The following table gives the total tuyere area for cupolas ranging from 24 to 72 inches.

Diameter of Cupola.	Area of Tuyeres.	No. of Tuyeres.
24 in.	24 sq. in.	2
30 in.	75 sq. in.	3
36 in.	108 sq. in.	4
42 in.	174 sq. in.	6
48 in.	204 sq. in.	6
54 in.	312 sq. in.	8
60 in.	400 sq. in.	8
66 in.	440 sq. in.	8
72 in.	550 sq. in.	10

For sizes with a greater diameter than 60 inches it is customary to keep the diameter 60 inches at the windbelt or tuyeres and increase to the full diameter of the cupola above. This is done because a diameter of more than 60 inches at the tuyeres does not permit the air to reach the center of the cupola, the result of which is imperfect combustion. This form of construction is shown in Fig. 2.

The iron is drawn out of a spout, located at the bottom of the cupola as shown in Fig. 1. A peep hole is placed in the windbox and covered with mica through which the amount of accumulated iron may be noted.

Melting Iron. We now come to the preparation of the cupola and the melting of the iron. The first thing to be done is to enter the cupola and daub the places of the lining that have been burned away. Fire clay mixed with a small quantity of sharp sand is used. It should never be put on in greater thickness than one inch. When this is insufficient to prevent the shield from becoming red hot the cupola should be relined. After the inside has been cleaned of adhering slag and daubed, the bottom doors are closed and propped. Upon the bottom a protection of sand

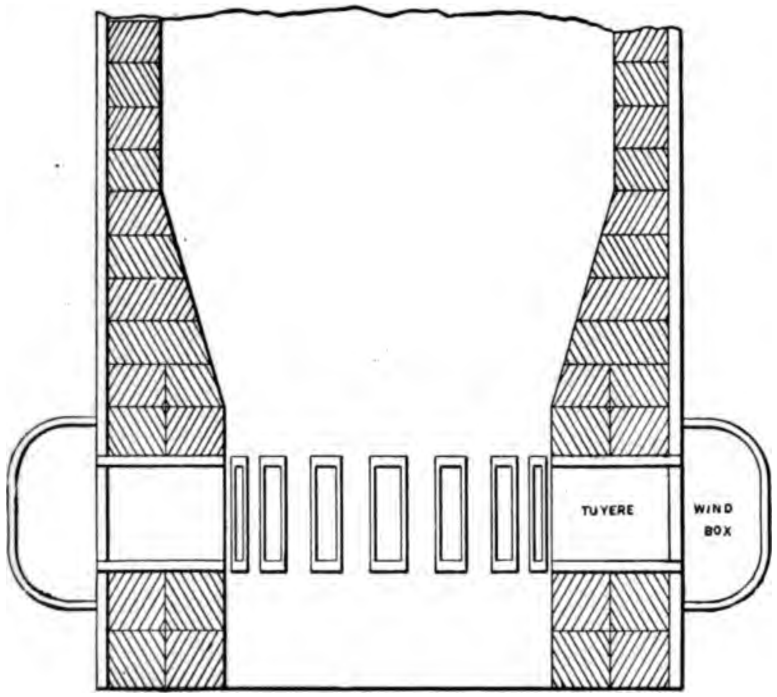


Fig. 2.

and cinders is placed and rammed down. It is then coated with a thin layer of fire clay to prevent its washing away. The front is built up with fire clay and the spout lined with the same. It is best to build a small fire of charcoal in the spout, to dry it, before the charge is put in.

The Bed is the name applied to the fuel that is first put in the cupola. The work of forming the bed should be carefully done. First some shavings are placed near the tap hole and upon these enough perfectly dry wood to ignite the main fuel. Either coal or coke may be used for the bed. The depth will be less with the former than with the latter. If coal is used Lehigh lump anthracite will be found to be the best. If coke, use large pieces of Connellsville. The bed should be made 12 inches thick for coal and 18 inches for coke.

Charging. The first charge or layer of iron is thrown in on the bed. It usually amounts to about three times the weight of fuel. Thus, in a 42-inch cupola, the bed would consist of about 520 pounds of coal upon which 1,560 pounds of iron would be thrown for the first charging. If the cupola is in good working condition the successive charges may be in the proportion of about one pound of fuel to 9½ pounds of iron. Thus, for a 42-inch cupola the charges should consist of about 400 pounds of fuel and 3,800 pounds of iron.

Melting. After the cupola has been filled with alternate layers of fuel and iron to the charging doors, it is ready for lighting. As the cupola has been daubed with damp materials, it is necessary that it should be dried before the blast is put on. The fire is, therefore, usually lighted at the vent hole about an hour and a half or two hours before the pouring is to begin. This kindles the bed, heats the cupola and first charge of iron; besides it either ignites or heats the fuel above. About twenty minutes before pouring is to begin the blast is put on.

The Blast is usually supplied by a fan blower which should be driven by an independent engine. The pressure of the blast is dependent on the size of the cupola. It varies from 6 to 16 ounces per square inch. The lower pressure may be used on 24-inch cupolas and the higher on 72-inch. It is necessary that the pressure should be sufficient to carry the air to the center of the cupola. For a cupola 42 inches in diameter the pressure should be 10 ounces.

In about five minutes after the blast has been applied the iron will begin to "come down." As the tapping hole is still open the iron first melted will flow out. This should be allowed to continue for a few minutes. The first iron to come down is not very hot. If the tapping hole were to be plugged at once, the iron would chill over the inside and choke it. When the iron is flowing freely the tapping hole is plugged with a piece of fire clay. This is done by fastening the clay on the end of a rod and jamming it into the hole. When this has been done the melted iron will accumulate in the bottom of the cupola and the lowest layer of fuel will float upon it. Strict watch is kept through the peep hole and when a sufficient quantity has been melted to fill the ladles, an iron bar is rammed through the tapping hole and the iron drawn off. When the cupola has been emptied the hole is again plugged so that the iron may accumulate.

As the iron comes down and the fuel is burned, fresh charges of both in alternate layers are thrown in at the charging door.

After all the iron of the last charge has been melted and drawn off and all the fuel burned, the prop supporting the bottom doors is knocked away. These fall and the contents of the cupola is dropped upon the floor, whence they must be cleared away after cooling.

Besides the fuel and iron that are used for melting, it is sometimes advantageous to use a flux. A flux is "a substance that promotes the fusing of metals." The object of using a flux in a cupola is to separate the impurities from the iron as well as to make it more fluid. The materials most commonly used for this purpose are oyster shells and marble chippings. Limestone, as in blast furnaces, is also used. The proportion to be used is about six pounds of oyster shells per melted ton of iron. Where the iron is clean and it is not necessary to use a flux it will be found advantageous to throw in a shovelful of oyster shells or marble chippings. This helps clean out the cupola.

Sand. The greater portion of all foundry moulding is done in sand. The sand used for this purpose must have certain peculiar properties. It should have a uniform grain, have some adhesive qualities, and be infusible at high temperatures. A failure to possess the first quality will make even ramming difficult or impossible. If it will not adhere, when rammed, the mould will fall to pieces. If it is not infusible, it will melt under the high temperatures to which it will be subjected and ruin the casting. A good moulding sand should, therefore, consist mainly of silica. Silica is one of the most infusible of the elements. The sand is made adhesive by mixing with it a little magnesia or alumina, usually the latter. It is found as an oxide of aluminum in the form of a clay. Moulding sands are found in various parts of the country. They are found in Canada, Central New York and New Jersey. Any sand containing limestone should be rejected.

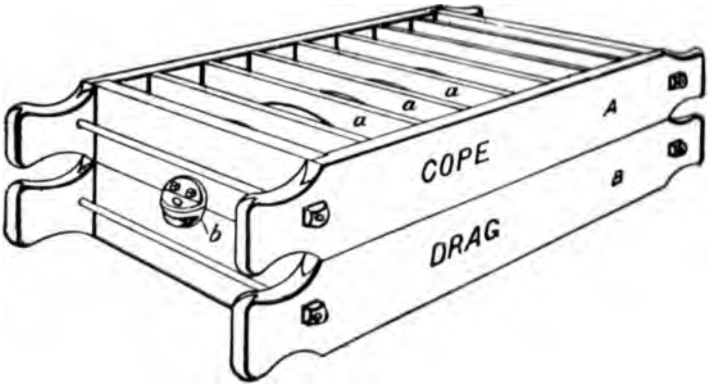


Fig. 3.

Cutting Up Sand is the process by which sand is worked into condition for use in the moulds. It is now sometimes done by special machinery. Ordinarily it is heaped in winrows across the floor of the foundry, pails of water are thrown over it and it is then shoveled back and forth until the moisture is evenly distributed. No rule can be given for the quantity of water to be used. The sand should be brought to about the same condition of dampness as that prevailing six or seven feet below the surface of an ordinary sand bank.

Flasks. A flask is the frame in which the sand is held while the mould is being made. It also usually holds the sand until the iron has been poured. They vary greatly as to form and size.

Flasks are often made of wood, but when many castings are to be made from any one pattern it is better to use cast iron. The ordinary form of wooden flask is shown in Fig. 3. The upper portion A is called the *cope* and the lower portion B is the *drag* or *nowel.* The difference is that the cope is provided with a number of crossbars *a a.* These bars provide surfaces to which the sand adheres when the cope is lifted from the pattern. The drag has no crossbars because it is only lifted or moved when there is an opportunity to clamp a moulding board on each side of it to hold the sand in position. In order to insure an accurate registering of the two parts of the flask, a dowel pin and plate is attached to each end as shown at *b* Fig. 3.

The frame of the flask should be made of sound wood about 1½ inches thick and of a width suited to the size of pattern to be moulded. It should be tied together with bolts to prevent breakage. The bars are made of thinner material. They may be from ¾ to 1 inch in thickness.

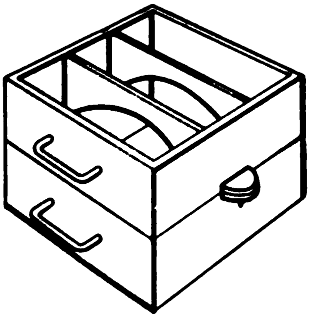


Fig. 4.

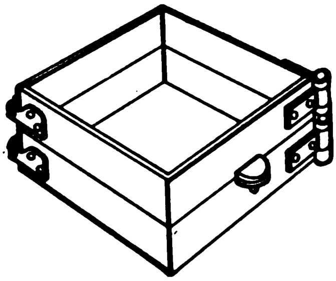
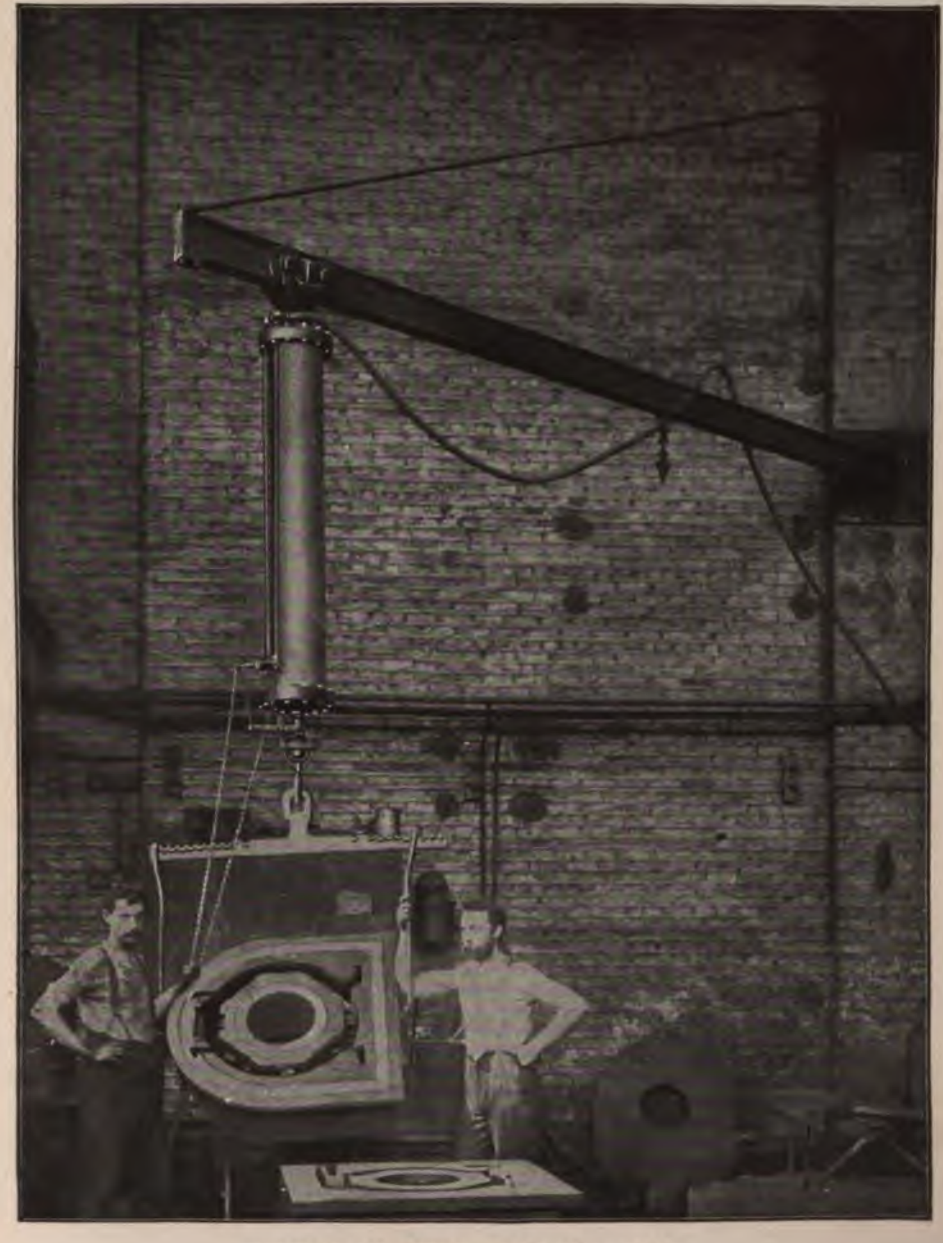


Fig. 5.

Iron flasks (Fig. 4) are made of cast iron. The thickness of metal ranges from ½ inch upward, according to the size of the flask. The bars of the cope for small flasks may be made ⅜ inch thick. The edges of the drag and cope should be planed where they come together. Dowel pins should be fitted into lugs cast on the side of the flask so that the mould will always register accurately.

The size of the flask chosen for any piece of work, should be such that a thickness of from at least 2 to 3 inches of sand should



WHITING AIR HOIST, HANDLING FLASK.
Foundry of Western Electric Company.

be upon all sides of the pattern. This thickness must be increased as the weight of the casting increases.

For very light work snap flasks are used. These open out and may be removed from the sand before the metal is poured. It is thus possible to make a large number of moulds in a single flask. This saves in the original investment of the foundry. An ordinary snap flask is shown in Fig. 5.

Large flasks are usually provided, both in the cope and drag, with trunnions by which they are raised and moved. They should also be strengthened at the edges as shown in Fig. 6.

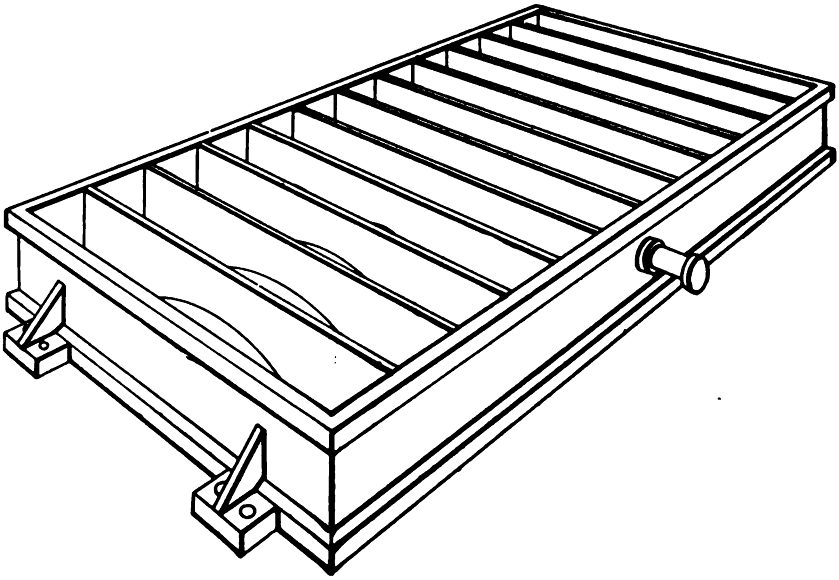


Fig. 6.

Flasks are also made with the sides hinged; for dressing they may be turned down with a portion of the sand.

Tools. The moulder's tools are of the simplest character. They should, however, be well made and receive proper care. Some are provided by the employer and some by the moulder. Those usually supplied by the employer are water pails, shovels, swabs, riddles, bellows and rammers. There ought always to be an ample supply of these tools so that no one need be idle. The pails are used for wetting down the sand previous to cutting up, etc. The shovels are for cutting the sand, throwing it into the riddles and similar work; the swabs serve to moisten the sand in the moulds when finishing. The riddles are the sieves through which the sand is sifted upon the patterns so that when the ramming is done it will be light and even in its texture and free from lumps. The bellows serve to remove the dust and loose sand that may have accumulated in the recesses of the mould while in course of preparation.

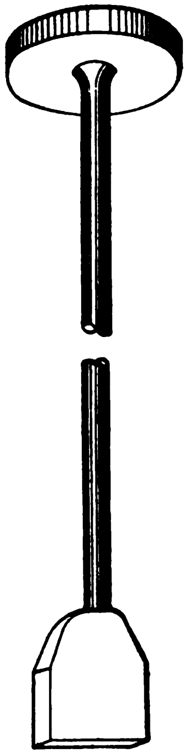


Fig. 7.

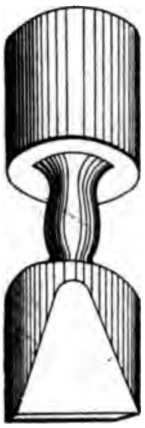


Fig. 8.

Fig. 9.

The rammers vary in length, weight and form in accordance with the work to be done. The general forms of rammers are shown in Figs. 7 and 8. The quality of the casting depends upon the weight and form of the rammer, and the force of the blow. For ramming moulds that are upon the floor a rammer as shown in Fig. 7 is used. It is usually made of iron and its weight depends upon the depth of sand to be rammed. For ordinary work this weight should be about 9 pounds. One end is flattened and from 3 inches to 4 inches in diameter. The other end is wedge-shaped with a rounded edge. The wooden rammer shown in Fig. 8 is for bench work. When such rammers are used one is usually held in each hand. It is, therefore, used for light ramming of small work on a thin body of sand.

The tools of the moulder's personal kit are small, light and simple. First he should have a liberal supply of vent wires of various sizes. These should be from $\frac{1}{16}$ inch to $\frac{1}{4}$ inch in diameter. They are made of ordinary stiff iron or steel wire flattened at one end and filed into the shape of a spear head as shown in Fig. 9. His next implement is the trowel (Fig. 10) ; this tool is in constant use. Each moulder should have at least four of different sizes. Its blade is square or with a rounded end. It should be stiff with a perfectly smooth flat surface. The lengths should be from 4 to 7 inches. Such a trowel is used for slicking off flat surfaces. When it becomes worn and pliable it may be used on curved surfaces. Another form of trowel is of the heart-shape (Fig. 11). The blade of this tool should be about 3 or 4 inches long. It is used for slicking off corners that cannot be reached with the square trowel. A combination form of heart-shaped and square trowel is shown in Fig. 12. This is usually a light tool with blades from 2 to 3 inches in length. Smoothers with the handle set at an angle as in Fig. 13, serve the purpose of the trowel where the mould cannot be reached by the latter. They should be from $\frac{1}{2}$ inch to 2 inches in width. Sometimes they are made with loose ends that can be screwed upon shanks.

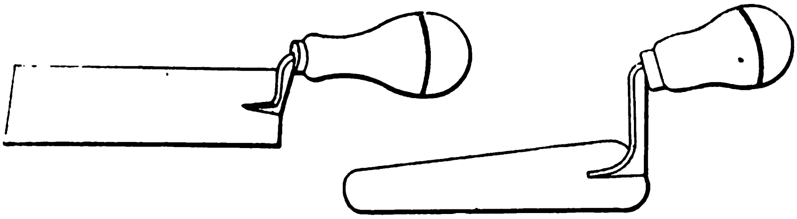


Fig. 10.

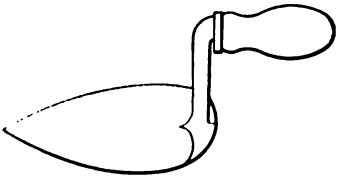


Fig. 11.

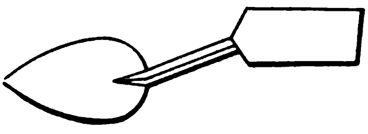


Fig. 12.

Lifters, as shown in Fig. 14 are important tools. They are used for *sleeking* and smoothing such portions of the mould as cannot be reached by the trowel. Their name is derived from their use, that of lifting out portions of sand that may have broken off from the mould. A modified form of smoother intended for rounded surfaces, and called a bead tool is shown in Fig. 15.

Still other forms of smoothers are shown in Figs. 16 and 17. These are for working into and over corners. Sometimes they are made with a concave or convex surface as shown in Figs. 18 and 19 and 20.

These are the principal types of tools used. They are of almost infinite variety of shape and design dependent upon the class of work. Where a moulder is engaged exclusively on one class of work he will need special tools, of the above general forms. These can best be designed to meet the necessities of the work in hand.

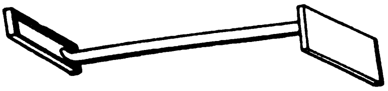


Fig. 13.

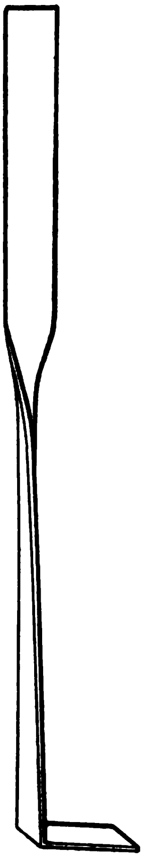


Fig. 14.

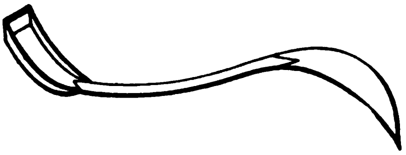


Fig. 15.

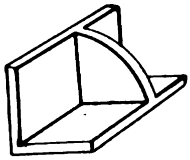


Fig. 16.

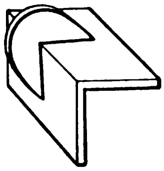


Fig. 17.

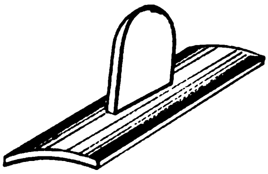


Fig. 18.

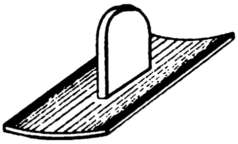


Fig. 19.

Moulding Sand. The qualities of ordinary moulding sand have already been given as infusibility and adhesiveness. Such sand, when used in its natural condition is called green sand. Green sand moulding is most extensively practiced. In many foundries it is used exclusively.

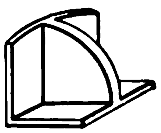


Fig. 20.

Loam is usually made in the foundry where it is used. It consists of sharp sand, moulding sand, manure and clay wash. The best way of mixing the loam is by the use of a mill. Loam mixing mills are practically the same as flour mills. Each has its upper and lower stones. Grindstones are, however, used instead of burr stones. When the loam is mixed by hand the mixture is beaten with an iron rod as it lays upon an iron or wooden bench. The mill is the better means of mixing.

The ingredients of loam vary with the purpose for which it is intended and also with the method of mixing. When ground in a mill a good proportion is: sharp sand 7 parts, manure 2 parts, moulding sand 2 parts, mixed with a thick clay wash. Clay wash is made by stirring ordinary blue clay in water. A thick wash is obtained by using a surplus of clay, and stirring frequently. When the loam is mixed by hand the proportions vary somewhat. They should be: sharp sand 5 parts, moulding sand 2 parts and manure $1\frac{1}{2}$ part, mixed with a thick clay wash. The sharp sand is used as a regulator for the moulding sand. The more clay there is in the moulding sand the greater the quantity of sharp sand that must be used. Experience alone can tell the exact ratios. A skilled workman can tell by the feeling as to whether the loam is properly mixed or not. A practical test is to take a well-dried lump and drop it in molten iron. If the iron boils after the first bubble, the mixture is too dense and contains too much clay. In this case more sharp sand must be added.

Dry sand is the name applied to a class of moulding where the moulds are baked in an oven before being used. The most common example of dry sand moulding is that of cores. The great majority of all cores used are made of dry sand. Loam cores are sometimes used in green sand moulds. Dry sand cores and moulds are made of sharp sand with a binder to cement the grains together. Good sharp sand should be free from clay. The grains should stand out separately and distinct from each other. It should consist, as nearly as possible, of pure silicon. The best of sharp sand may be obtained from any of three sources; the beach where it has been washed by the waves of the ocean; river beds, where it has been cleansed by the scouring action of the stream and the artificially washed sand taken from banks.

The binders used as cement for cores are beer, flour, molasses, resin, clay and glue. Those in most common use are flour and molasses. As in loam moulding, the proportions of the ingredients used in cores vary with the work to be done. A good common mixture is the following: 1 part flour, 7 parts clean sharp sand and 3 parts fine moulding sand, mixed with enough water to dampen. A tougher core can be made of 12 pounds of sharp sand, 5 pounds of moulding sand, 2 pounds of very finely ground resin and $\frac{1}{4}$ pound of flour. This should also be mixed with water in which molasses has been stirred in the proportion of 1 gill to the quart. The ingredients should be carefully mixed so that each portion is evenly distributed throughout the mass.

Cores are made in core boxes. The construction of these boxes is fully described in "Pattern Making." After the core mixture is made it is rammed into the core boxes, turned out on the bench and then carefully and thoroughly dried in a core oven. As already stated in "Pattern Making" cores are frequently made in halves and pasted together. The paste is made of a cheap grade of wheat flour. After the core or dry-sand mould has been dried it should be blackened so as to present a smooth surface to the iron. The blacking may also be applied before the core is baked. Preparation of the blacking calls for the same skill as that of the core and loam mixing. A good blacking may be made of 1 pound of black lead, 1 pound of charcoal blacking, 4 pounds of Lehigh blacking, mixed with beer or molasses water and a little fire clay. In mixing molasses water for this purpose, use about one-half a pint of molasses in a pail of water.

Core ovens are used for drying cores and moulds. There are many styles of ovens. Where large and small work is done there should be two ovens for the two classes of work. It is uneconomical to heat a large oven in order to bake small cores. The oven and fireplace are usually in the same enclosure. Thus the products of combustion come in contact with the cores without injury to them. A convenient form of oven for baking small cores is shown in Fig. 21. It consists of a number of circular shelves mounted on a central shaft which is held by a step at the bottom and a bearing at the top. By turning the shelves any parts of them may be brought opposite the door for loading or removing the cores.

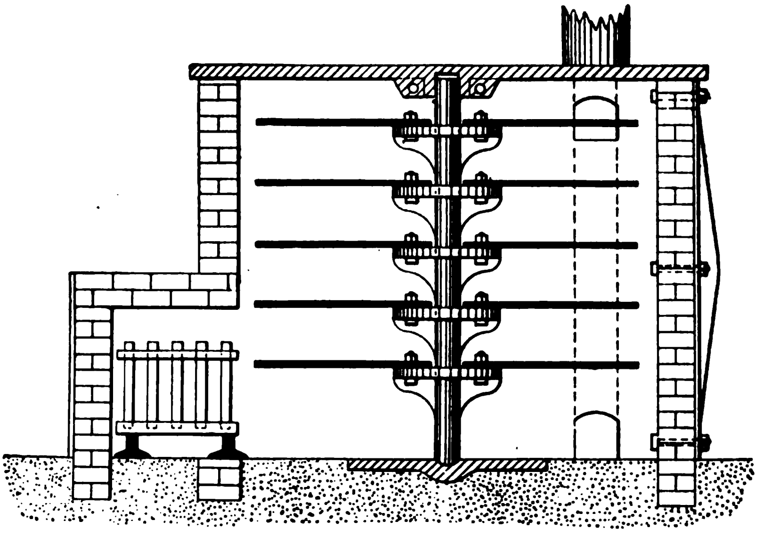


Fig. 21

The shelves should be in the form of gratings so that the hot gases may pass through and around the cores. The furnace and stack should be arranged so that the hot gases and products of combustion are made to pass across the oven.

Large ovens are made with a traveling carriage. The cores are loaded when the carriage is outside the oven. The carriage is then run in, the doors closed and the fire lighted. Such an oven is shown in Fig. 22. The furnace is located beneath the floor of the oven. There are racks upon each side upon which cores may be dried as well as upon the carriage.

Firing. The best fuel for firing a core oven is coke. Wood is very frequently used, as is also hard and soft coal. It is desirable to have a steady fire. Wood and soft coal do not make steady fires and they require constant attention. Hard coal makes a good, hot fire, but it is expensive. The time required to dry a core varies from one to fourteen or more hours, according to its size. Where large cores are to be dried it is customary to bake them all night. In such cases the dampers of the furnace must be arranged so that the fire will burn steadily for a long time without attention.

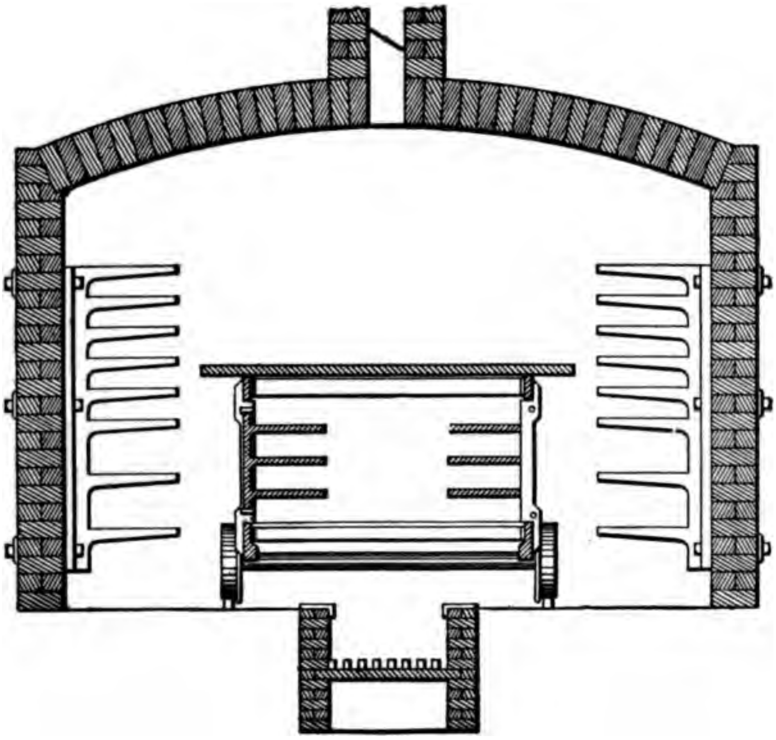


Fig. 22.

Dry sand moulds are baked in the same way as cores, except that, in some instances they are dried in position. Loam moulds are also dried in position.

Moulding. The work of the moulder differs from that of the carpenter, blacksmith or machinist. The blacksmith can see with each blow of his hammer how his work is progressing; the machinist has his work constantly under his eye so that he sees just what is being done even with the finest cut. But with the moulder, the progress of his work to some extent is not visible. He makes his moulds and cores but the progress of his work cannot be fully determined until the casting is completed. For this reason the moulder must work with great care; his skill comes largely from his own experience and that of his fellows. Knowing "the reason why" is of as much benefit in this work as in any other.

It is impossible to give explicit directions as to the force of the blow to be given to the rammer. This must be left to the judgment of the workman. He will soon learn to gauge the blow according to the work to be done. The general principles of ramming may be roughly stated to be:

The deeper the body of sand the harder the ramming.

The hardest ramming must be done near the lowest point of the sides of the moulds.

The lightest ramming should be done near the highest point of the sides of the mould.

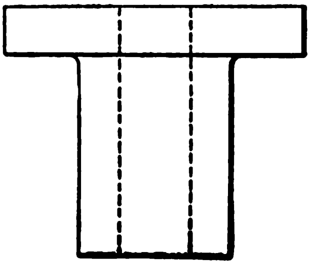


Fig. 23.

To these statements it may be added, that light ramming continued, until the sand is in a proper state of compactness, will give better results than hard ramming for a shorter time. Evenness in the blows is of the greatest importance. Any bottom section of a mould that is to have a pressure put upon it by a rapid flow of molten metal will stand harder ramming than where it is to be covered over slowly. Hard ramming causes more trouble than light. The rammer should never be allowed strike the pattern.

The general method of making a mould is the same for all patterns, but there is an endless variety in the detail. As a simple example take the gland illustrated in Fig. 56 of "Pattern Making" and reproduced here in Fig. 23.

First select a flask of a suitable size. It should be at least 8 inches larger each way than the diameter of the pattern, and 2½ inches deeper. This leaves 4 inches of sand upon each side and 2½ inches at the bottom. The flask consists of the two parts, the cope and drag or nowel to which must be added a moulding board. This moulding board is used repeatedly for successive moulds. It consists of smooth boards fastened together with cleats as in Fig. 24, and has one plain surface. The moulding board is laid in a level position on the floor with the plain surface uppermost. The pattern is placed in the middle of the board, with the side down which is to be at the parting line between the cope and drag. The drag should then be set on the moulding board (Fig. 25) bottom up. It must be adjusted so as to stand evenly about the pattern. Fill a riddle with sand and sift it over the pattern until it is entirely covered. Where there is to be a core formed of green sand, as in this case, the hole in the pattern must be filled with sifted sand. Tuck this sand down snugly into the hole before commencing to ram. When the ramming is completed scrape off the sand that projects beyond the edge of the drag, lay another board on top to hold the sand in position, and clamp the drag and the two boards together as in Fig. 26.

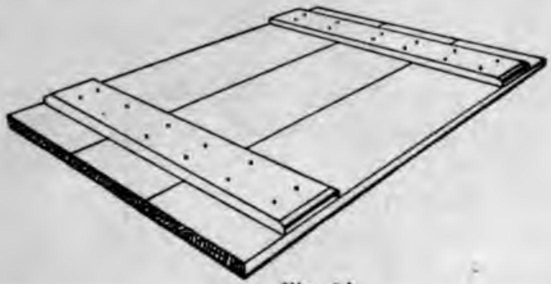


Fig. 24.

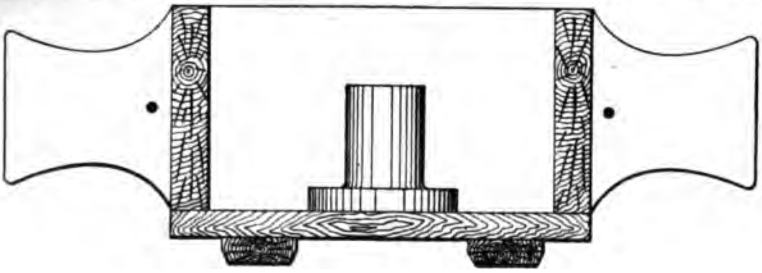


Fig. 25.

The **clamps** used for this purpose should be strongly made of iron about 1 inch square and of the shape shown in Fig. 27. They should be long enough to slip easily over board and drag and be held by wedges driven in as shown in Fig. 26.

When the drag and moulding boards have been clamped together the whole should be turned over and the moulding board removed. This exposes the surface of the sand with the pattern on top. Examine the mould carefully to see if the sand lies close about the edges of the pattern. If it does not, mend it by the addition of sand where needed. Do this work with the fingers and only use the trowel for smoothing.

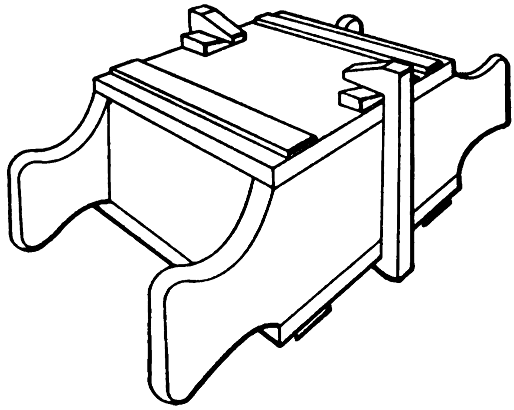


Fig. 26.

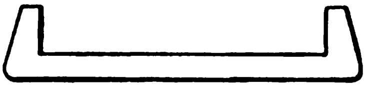


Fig. 27.

After this face of the mould is made all right, sprinkle the whole surface with *sharp* sand, which is then called *parting* sand. This will prevent the sand of the cope from adhering to that in the drag. If the sand adheres the cope and the drag can not be separated and the pattern removed without injuring the mould.

After placing the cope in place, sift in enough sand to cover the upper surface of the drag, then shovel in enough to fill the same and ram. In ramming the cope be careful that the rammer does not strike the bars.

When the cope has been rammed and the superfluous sand removed from the top, it is lifted off and laid bottom up. The parting sand is then dusted from the faces of cope and drag. The pattern may now be removed. It is usually advisable to wet the swab and draw it around the edge of the pattern. This stiffens the sand and prevents it from breaking away when the pattern starts. Great care should always be exercised in the use of the swab. If too much water is used it will cause blowing when the iron is poured. If it is necessary to make the sand very damp, it should be dried somewhat before pouring. The pattern is lifted out of the sand by screwing a lifter into the lifting plate, if there is one. If no lifting plate has been put on the pattern, a sharp pointed lifter is driven into the wood. This is rapped gently to and fro, while being pulled. As soon as the pattern starts the rapping may stop. Be careful that the pattern is lifted vertically and does not strike the surface of the sand. The mould is now made and only requires finishing and blacking.

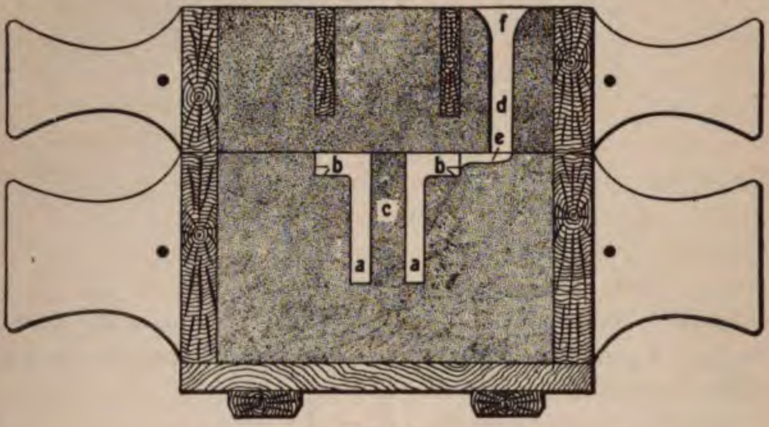


Fig. 28.

Blacking is a mixture of anthracite coal, charcoal and black lead, all especially prepared for the purpose. A good mixture may be taken as 2 parts of Lehigh blacking, 1 part charcoal blacking, and 1 part of German or American black lead. The blacking may be applied either wet or dry. When applied dry it is put in a cotton or coarse linen bag and dusted over the surface of the mould. When blacking is to be applied moist it should be wet with beer or molasses water. It is applied with the swab. The object of blacking is to give a fine, smooth surface to the face of the casting and to prevent the sand from adhering to the metal.

In the case of the moulding of the gland, where the metal is light the blacking is usually applied dry because the parts *a a* (Fig. 28) in the depth of the drag are not accessible either to the swab or the smoothers. After the blacking has been shaken over the whole surface of the mould the exposed parts *b b* (Fig. 28) may be sleeked over with the smoothers. The mould may then be closed, as shown in section, Fig. 28. In which it will be seen that the mould is wholly imbedded in the drag. The core is formed by the green sand *c*. The cope serves merely as a cover to prevent the overflow of the iron.

The passage by which the molten metal reaches the mould is made through the cope. This is done while the cope is being rammed. A stake (Fig. 29) about 1½ inches in diameter and long enough to reach to the top of the cope is stuck in the upper surface of the sand of the drag. This projects up through the cope and the sand is rammed about it as though it were a pattern. Before the cope is lifted off this is pulled out leaving a hole in the sand of the cope as at *d*, Fig. 28. From the bottom of this hole a groove *e* is cut out of the sand leading to the mould. The top of the hole *f* is usually enlarged so as to secure a wider opening into which to pour the metal. The gate *d* should not lead directly into the mould. The force of the falling metal dropping upon the face of the mould would wash it away and ruin the casting. This is called the gating of the casting. There are many ways of gating that are adapted to different classes of work, some of which will be described later.

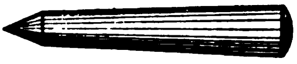


Fig 29.

After the mould has been closed as in Fig. 28, the cope and drag must be clamped together. This is done in the same way as shown in Fig. 26 where the drag and two boards are clamped together. Clamping is only used on small moulds. In large moulds the cope is held down by weights.

Weighting or clamping is necessary in order to prevent the upward pressure of the molten iron from forcing apart the cope and drag or floating the former. The upward pressure on a cope depends upon the height of the iron above the upper surface of the mould and the area of the latter. Thus in Fig. 28 the upward pressure on the cope depends upon the height of the top of the gate at *f* above the top of the flanges at *b* and the surface of the latter. The reason for measuring to the top is, that the gate is always filled with metal when pouring which is allowed to cool with the casting. This metal is afterwards broken off and remelted. It is called a *sprue.*

To Calculate the Upward Pressure on a Mould. The upward pressure of molten iron upon a mould is calculated in the same way as the upward pressure of water upon any object submerged in it. The upward pressure of water is calculated by multiplying the height in feet, by the weight of a cubic foot of water and this product by the area in square feet upon which the pressure is exerted. Iron is 7.2 times heavier than water and the cubic inch is used as the basis of calculation. The rule, therefore, to calculate the upward pressure of molten iron is: *multiply the depth in inches by the weight of a cubic inch of iron and this product by the area, in square inches, upon which the pressure acts.* The weight of a cubic inch of cast iron may be taken to be .2607 pound.

EXAMPLES FOR PRACTICE.

1. What is the pressure per square inch of section in a mould at a depth of 8½ inches below the surface of the iron?

Ans. 2.2+ pounds.

2. What is the total pressure upon a circular area 6 inches in diameter and 11 inches below the surface of the iron?

Ans. 81.+ pounds.

4. What is the pressure upon a rectangular surface measuring 12 inches by 14 inches and 13 inches below the surface of the metal?

Ans 569+ pounds.

The pressure of molten iron is exerted in every direction in exactly the same manner as water. (See Mechanics, Part II, page 42). The height of the metal must be taken from the surface of the gate. Let Fig. 30 be the section of a mould. The upward pressure per square inch of section at *a* will be equal to the depth *h* multiplied by .2607. The lateral pressure per square inch at *b* is equal to the depth h'' multiplied by .2607 and the downward pressure per square inch at *c* is equal to the depth h'

multiplied by .2607. The total lateral pressure is equal to the area of the sides multiplied by the average pressure upon them. In Fig. 30, let the mould be 8 inches square, 7 inches deep and the gate (h) be 6 inches long. If b is midway between the surfaces a and c then

Area of a = 64 square inches.
Area of c = 64 square inches.
Area of b (one side) = 56 square inches.
Area of b (four sides) = 224 square inches.
Height h = 6 inches.
Height h' = 13 inches.
Height h'' = $9\frac{1}{2}$ inches.

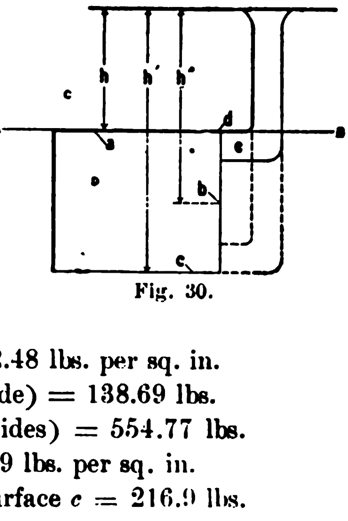


Fig. 30.

Let the gate at e be semi-circular and 2 inches in diameter, and the length at d be $1\frac{1}{2}$ inches.

Solving this in accordance with the principles set forth we have,

Upward pressure at $a = 1.56+$ lbs. per sq. in.

Total upward pressure on surface a = 100.11 lbs.

Average side pressure at b = 2.48 lbs. per sq. in.
Total side pressure at b (one side) = 138.69 lbs.
Total side pressure at b (four sides) = 554.77 lbs.
Downward pressure at c = 3.39 lbs. per sq. in.
Total downward pressure on surface c = 216.9 lbs.
Upward pressure on surface d = 4.69 lbs.

In Fig. 30 let A B be the parting line between the cope and the drag; C be the cope and D the drag. It is evident that the pressure at b is sustained by the sand which is held by the sides of the drag. The pressure on the bottom c is carried by the moulding board and floor. Therefore, it is only the upward pressure at a and d that must be balanced by clamps or weights in order to prevent the cope from being lifted by the iron. In the case cited this amounts to

$$100.11 + 4.69 = 104.8 \text{ pounds.}$$

Hence a weight of at least 104.8 pounds must be placed on the cope to hold it down. Practically this should be at least 150 pounds.

If however this same pattern were to be cast as in Fig. 31 where 2 inches project up into the cope; then *h* becomes 4 inches and the total upward pressure at *a* is 66.7 pounds.

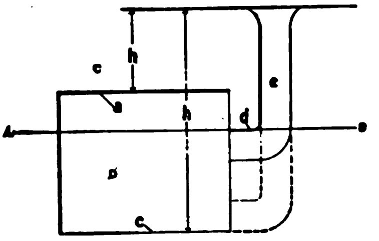


Fig. 31.

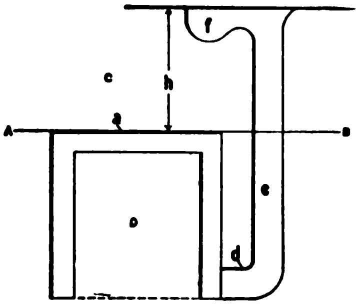


Fig. 32.

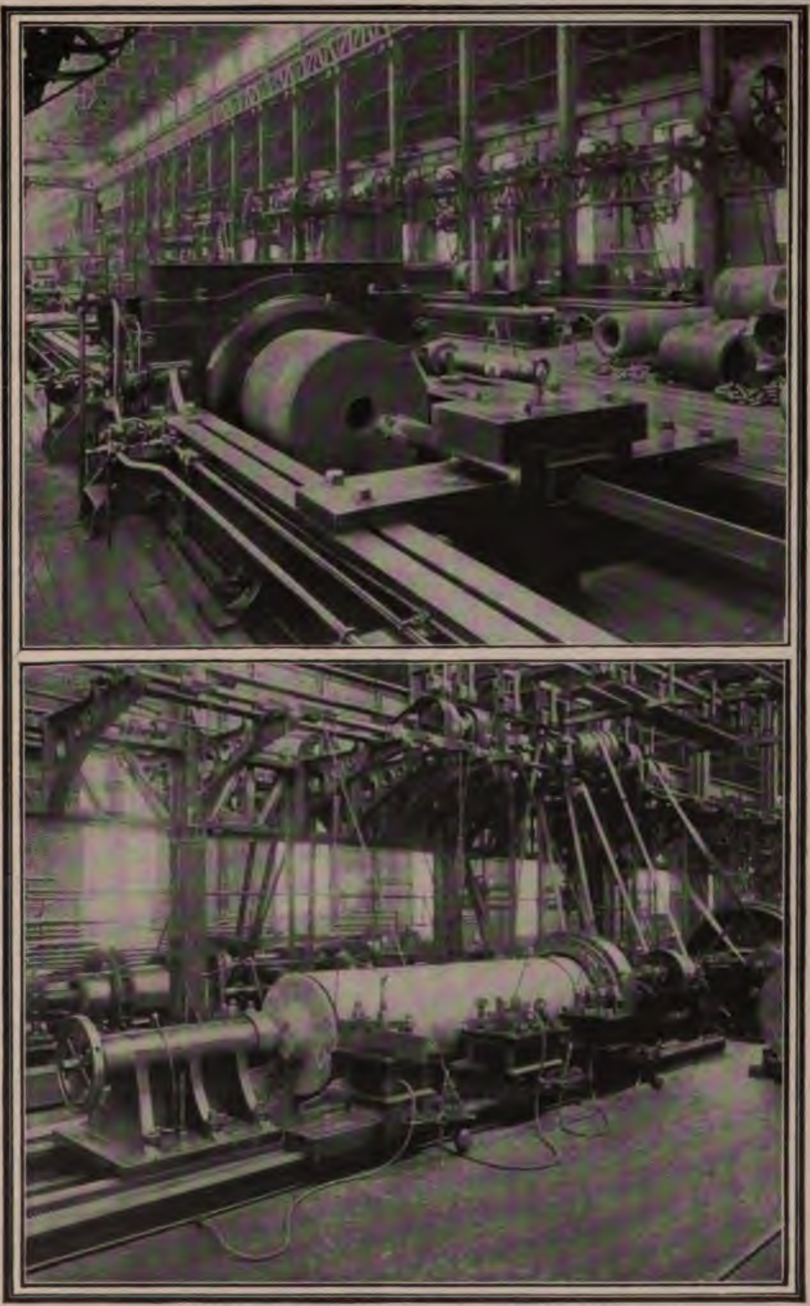
The total upward pressure on the cope is obtained by adding that at *d*, which remains the same as before. Hence, total upward pressure on cope = 66.7 + 4.69 = 71.39 pounds.

The greatest care must be exercised in these cases to determine what may be the depth of the surface acted upon below the upper surface of the gate. The way in which a pattern is moulded sometimes has an important effect upon the pressure on the cope. Suppose, in Fig. 32, we have a hollow cylinder of 8 inches outside diameter, 8 inches long and with a shell and bottom 1 inch thick. It is to be cast bottom up, with the face *a* on the parting line A B. Let the depth *h* of the gate in the cope be 6 inches. Then the pressure per square inch at *a* will be 1.56 pounds. As the area at *a* is 50.266 square inches, the total upward pressure is,

$$50.266 \times 1.56 = 78.41+ \text{ pounds.}$$

The point at which the gate enters the mould is of no moment in calculating the pressure. It is the depth of the surface below the top of the gate that is important. In Fig. 32, the surface *d* is 7 inches below the parting line. Hence the upward pressure at that point, per square inch, is,

$$.2607 \times 13 = 3.39 \text{ pounds.}$$



CUTTING AND BORING A FLUID-COMPRESSED INGOT
BETHLEHEM STEEL WORKS. N. Y.

As the area is the same as in Figs. 30 and 31, the total upward pressure at *d* is

$$3.39 \times 3 = 10.17 \text{ pounds.}$$

Total upward pressure on cope = 78.41 + 10.17 = 88.58 pounds.

If now the pattern is reversed and moulded bottom down, as in Fig. 33, a different pressure will be put upon the cope. The pressure at *a* is that due to the height *h* which is 6 inches, upon a ring 8 inches outside and 6 inches inside diameter. This is 34.3 pounds.

The pressure upon *a'* (the bottom of the cylinder) is that of a circle 6 inches in diameter, submerged to a depth of 13 inches below the upper surface of the molten metal. This amounts to 95.85 pounds. We therefore have,

Upward pressure at *a*	34.30 pounds.
Upward pressure at *a'*	95.85 pounds.
Upward pressure at *d*	10.17 pounds.
Total upward pressure at cope	140.32 pounds.

This is a difference of 51.74 pounds due solely to the method of moulding.

For light moulds no weight is needed. The two parts of the flask may be held together by clamps as in Fig. 26. In larger moulds, where the pressure would be apt to push the sand up out of the cope, weights must be used. The amount of weight to be used should be at least 50 per cent. more than the calculated pressure. The weight must resist not only the calculated or static pressure in the mould, but also that due to the momentum of the inflowing metal. This latter depends upon the height of the gate and the volume of the entering metal. For fety use an excess of weight. Pig iron is usually the most ient to use for weights.

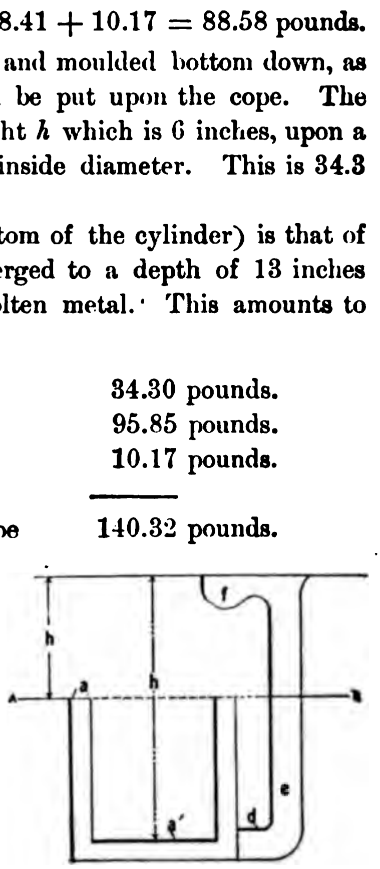


Fig. 33.

ig. It is as necessary that the mould shall be properly t it should be properly made. The gate is the passage left in the sand through which the metal flows to the mould. The following precautions must be taken in making the gate:

(*a*) It must be of such size that the metal shall flow freely through it without chilling.

(*b*) It must be of such shape that sand shall not be torn from its sides by the falling metal.

(*c*) It must allow the metal to enter the mould in such a manner that none of the sand constituting the latter shall be washed away.

In small castings one gate may be used. This gate may enter at the top of the mould or on the parting line between the cope and the drag. For heavier castings more than one gate must be used. The reason is that if only one were put in, it would have to be very large. This would involve a large inflow of metal which would wash away the sand. It is also desirable that the large moulds should be fed at different points. If the metal were poured into a large mould from one point only, it would be apt to chill before it reached all parts. This would produce a defective casting. The defect might consist of chilled parts or an incompletely filled mould. No fixed rule can be given for the number of gates. The number depends upon the size, shape and weight of the casting. The shape of the mouth of the gate also depends upon the weight of metal to be poured. For small castings it may be simply belled out as in Figs. 30 and 31. For larger castings or where the gate is deep, a basin should be formed in the sand of the cope at the mouth of the gate. Such a basin is shown at *f* in Figs. 32 and 33. The size of this basin depends upon the weight of metal to be poured.

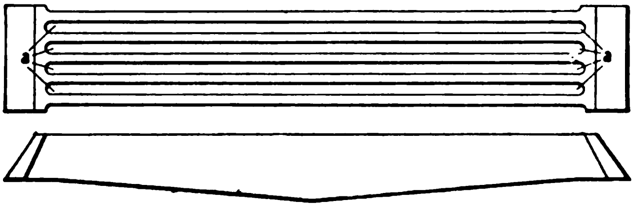


Fig. 34.

In general it is always well to make the gates as long as possible. Where a large amount of iron is to be run through a gate, it is well to protect the mould by placing cores against the pattern at the point where the metal will strike the sand. This may also be done by ramming a mixture of flour and facing sand against the patterns at weak points.

The size of the gate also depends upon whether the mould is to be poured rapidly or slowly. In the grate-bar Fig. 34, where there are a number of small cores, *a a*, the metal must be poured slowly. If it were to be poured in with a rush the cores would be washed away and the casting ruined. In Fig. 31 on the other hand, where there are no light cores the metal may be poured very rapidly. In Fig. 34 the iron should be poured hot and slowly. In Fig. 31 it need not be so hot and may be poured rapidly.

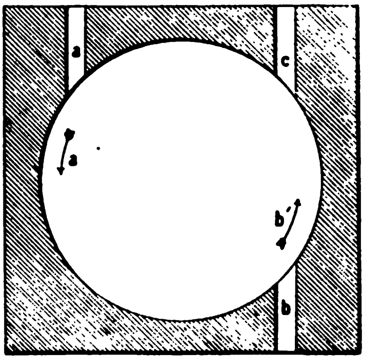


Fig. 35.

The point at which the iron enters the mould is of great importance. The method of gating shown in Fig. 33 is preferable to that of Fig. 31. In Fig. 33 the gate enters at the bottom of the mould, and sustains all the effect due to the falling of the molten metal. There is in this case little danger of washing away the sand of the mould. In Fig. 30 the iron falls from the point, where the gate enters the mould, upon the bottom *c*. The force of this falling metal will be likely to wash away the sand. This can be obviated in two ways; a dry sand core may be put in the bottom of the mould, or the gate may be led in at the bottom as shown by the dotted lines. The latter is the better method. Where moulds are very deep, even a dry sand core would be in danger of being washed away.

Where two or more gates enter a mould they should do so in such a way as to promote a circulation of the iron. An example is given in the round plate Fig. 35. If there are two gates entering at *a* and *b*, it is evident that they will have a tendency to cause the metal to circulate in the same direction, as indicated by the arrows *a'* and *b'*. If, however, the gates are placed at *b* and *c* the

[illegible]

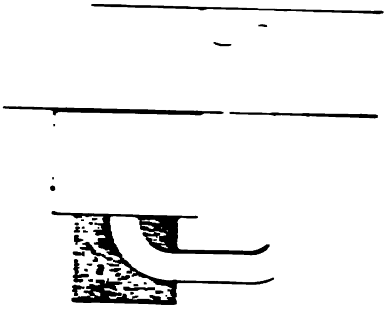


Fig. [illegible]

Weight of Castings. [illegible]

[illegible]

[illegible] This, however, will make the calculated weight of the casting greater than the actual weight, and is thus on the side of safety.

EXAMPLES FOR PRACTICE.

1. What is the weight of a flat plate of cast iron, 2 feet square and 1½ inches thick? Ans. 225 (nearly) pounds.

2. What is the weight of a cast iron cylinder 24 inches long; 12 inches outside diameter and [illegible] inches inside diameter? Ans. [illegible].15 (nearly) pounds.

In calculating the amount of metal to be melted or poured an allowance must be made for the weight of the sprues that fill the gates and are attached to the castings. These weights must be added to that of the castings. Where there are cores they must be deducted from the calculated weight.

Venting. The gases formed by the molten iron must be allowed to escape from the mould. The gases are produced by the decomposition of the organic matter contained in the sand and cores. This is due to the heat of the molten iron. Unless the gases are allowed to escape they will hold back the iron and cause an irregular casting. A larger quantity of gas is formed from dry than from an equal weight of green sand. This is due to the presence of a larger amount of organic matter, such as flour, molasses, etc., in dry than in green sand.

Venting is usually accomplished by pushing a vent wire (Fig. 9) through the sand of the cope at several places. The larger the dry-sand core used the greater the number of vent holes. Venting is very important in moulding. When it is found that the gases pass up through the iron, causing it to bubble at the mouth of the gate, the venting is insufficient. If a mould is rammed solidly the number of vent holes must be large. When sand has been used a number of times the organic matter is largely decomposed. Hence, old sand will produce less gas than new, and therefore, requires less venting. The venting should be done while the pattern is still in the mould. If the venting is not properly done, the pressure of the gas may be sufficient to throw the metal out at the gate.

Pouring. After the metal is melted it is drawn from the cupola into a large ladle. From this large ladle it is poured into smaller ones. These are taken to the moulds and emptied. They vary in size from the small hand ladle that may be carried when filled, by one man, to the ladle holding several tons that is moved by a crane. The iron as it comes from the cupola is usually too hot to be poured immediately. Cast iron melts at about 1500° Fahr. It is usually much hotter than this when it leaves the cupola; also when poured. The temperature at which it should be poured depends upon the kind of casting to be made. No definite rule can be given, but it is customary to have the metal at higher temperatures for the thinner castings. Moulds having thin cores or projections should be poured slowly with hot metal. Heavy castings with few or no cores may be poured rapidly with dull metal.

Ladles. As already stated, ladles are of all sizes. The ordinary ladle is made of cast iron and is freshly lined after each casting with fire clay. This lining is called *daubing*. The fire clay is mixed with water until it is in a plastic condition like putty. The interior of the ladle is then daubed to a thickness of from 1 to 2 inches. The daubing is thicker at the bottom than at the top, and should be spread smoothly. After the daubing a wood fire is built within the ladle. This serves to dry the clay. If it were allowed to remain damp the steam formed by the molten iron would blow the latter out of the ladle. Many serious accidents have been caused in this manner. The ladles that can be carried by hand are usually held in a frame as shown in Fig. 37. The ladle thus hung is usually carried by three men. One takes hold of the two handles of the fork at *a*. The other two take hold of the single bar at *b*. The object of this arrangement is to give the moulder, who carries at *a*, complete control of tilting the ladle and pouring of the metal. The lengths of the arms are proportioned to put approximately the same weight on each man. At the same time the moulder carries more than one-third of the weight because he is in a better position than the others to do so. Ladles small enough to be carried by one man have a single handle as at *b*.

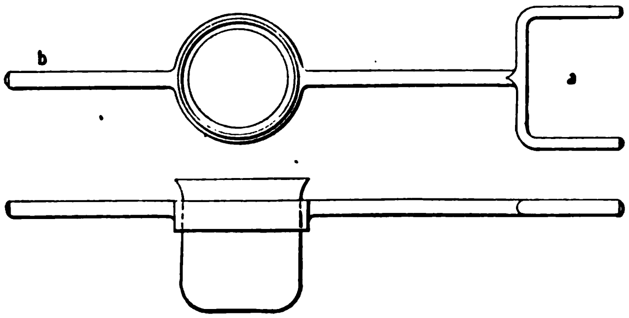


Fig. 37.

Grades of Iron. The grade of iron for a particular class depends upon the intended use of the casting. The natural grades of pig iron are varied by mixing with each other and by the addition of scrap. The pig irons are placed in one of three grades known as No. 1, No. 2 and No. 3. There is no absolute distinction between them for they merge into each other by imperceptible gradations. The metal, when cast, contains from three to five per cent. of carbon, besides such elements as silicon, sulphur, phosphorus and manganese. In some cases it also contains arsenic, copper, etc. Carbon is the distinguishing element of pig iron. It occurs in two forms; the combined, and graphitic or uncombined. The difference in the grades of iron depends upon the relative proportions of these two forms of carbon. A large percentage of the carbon in the soft, gray irons is in the uncombined form. In the hard, white irons this carbon is almost wholly combined. The carbon contained in cast iron never exceeds five per cent.

No. 1 iron contains the largest amount of uncombined carbon. It is of a dark bluish gray when broken. The fracture also shows numerous graphitic scales. This iron is weak and has a low tensile strength. It is used for light castings intended for ornamental work. Sometimes this iron contains so much uncombined carbon that, when melted, *kish* appears on the surface. *Kish* is a carburet of iron, which, when cold, appears in bright shining scales. In the ladle, as a liquid, it floats upon the surface. It possesses most of the properties of graphite but contains less carbon. When kish appears the iron is unfit for use.

No. 2 iron contains a smaller amount of uncombined and more combined carbon. The fracture is more regular than that of No. 1. The crystals are smaller and the color a lighter gray. It is harder and stronger than No. 1, and is used for the general run of foundry work.

No. 3 iron contains less uncombined and more combined carbon than either No. 1 or No. 2. The fracture is regular. The crystals are still smaller and the color still lighter than No 2. It is also more dense and stronger than No. 2. It is suitable for use in heavy work. When melted it is less fluid than either of the other two. It is too hard to be readily worked in a machine.

There are still higher numbers. These are known as forge irons and are suited only for puddling.

The effect of the other impurities, such as silicon, sulphur, phosphorus and manganese is also very marked. These always exist in much smaller quantities than carbon. In Lake Superior charcoal iron there will usually be found about 2.25 per cent. of silicon ; .03 per cent. of sulphur; .10 per cent. of phosphorus and from .15 to .18 per cent. of manganese. When silicon occurs above a certain per cent. the iron is weakened. If this proportion is large the iron is made hard and brittle. Small quantities of sulphur strengthen ; phosphorus weakens iron, and makes it more fluid when melted. Manganese gives iron a white appearance and renders it more brittle. Where iron is to be cast in a chill, as explained later, the addition of powdered manganese tends to increase the depth of the chill.

Any degree of hardness and strength may be obtained by mixing the above-described irons in suitable proportions. Where iron is to be subjected to blows as in heads and anvils of steam hammers, there should be a preponderance of No. 3. For steam engine cylinders and all castings to be machine finished, where the surface must be hard and smooth there should be a preponderance of No. 2. The iron selected should be compact and free from an excess of uncombined carbon. It may be hardened by mixing a little scrap with it.

Remelting iron tends to harden it, to drive out the uncombined carbon and to give it the characteristics of No. 3. When iron is said to be a good *scrap carrier*, it is meant that it contains a considerable percentage of uncombined carbon. This excess of uncombined carbon makes up for the deficiency of the same in the scrap. The casting produced by the mixture has the characteristics of castings made from No. 2 iron of good quality, except that it is not as strong.

The tensile strength of cast iron varies from 20,000 pounds to 40,000 pounds per square inch of section.

Cooling of Castings. As stated in "Pattern Making," it is very desirable that a casting should be made as nearly of a uniform thickness as possible. Where the thickness of the metal varies, the thin portions cool more quickly than the thick. Internal stresses are thus set up in the metal which may cause a fracture. If the casting is not actually broken it is strained so that it is not strong enough to stand the load which it was calculated to bear. This is shown in Fig. 38 in an exaggerated form. The thin rim of the pulley cools first. It becomes hard, solid and fixed while the heavy spokes are yet at a high temperature. As the spokes cool they contract. This contraction of the spokes pulls the rim toward the center and probably results in a fracture.

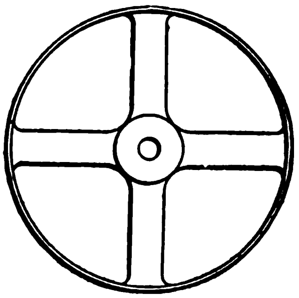


Fig. 38.

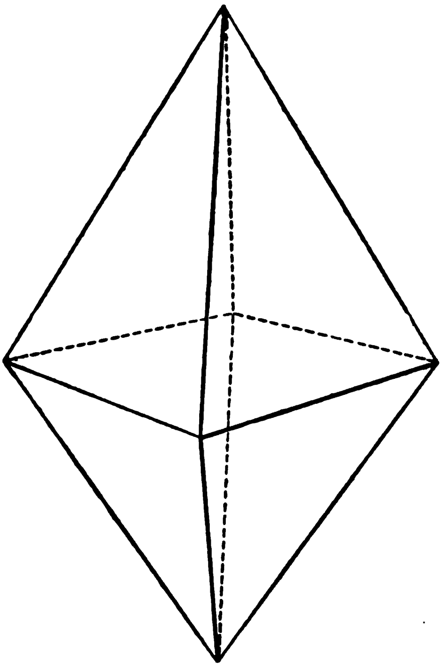


Fig. 39.

It is not always possible or desirable, however, to make castings of a uniform thickness. Where the thickness does vary the cooling may be made uniform. This is done by knocking the sand off from the casting and exposing the thick parts to the air while the thin parts are kept covered by the sand. The heat is, therefore, retained in the latter and its radiation checked, while the radiation is facilitated in the thick portions.

Effect of Shape on Castings. In "Pattern Making," the necessity of fillets in all corners was stated. The reason for this is that any sudden variation of form tends to weaken a casting whether the thickness varies at that point or not. When cast iron changes from the liquid to the solid state it crystallizes. The crystals thus formed are either of a right square-based octahedral form as in Fig. 39 or that of a regular octahedral as in Fig. 40. These crystals always arrange themselves with their axes perpendicular to the cooling surface. When the casting cools slowly the crystals are larger than when it cools rapidly. The larger the crystals the softer the metal. Fig. 41 shows the effect of cooling when the corners are rounded, also when they are sharp. It will be seen from this representation of the arrangement of the crystals when cooling, that there is a line connecting the two sharp corners *a* and *b* where their axes lie at right angles to each other. The casting will be weak along this line. On the other side where the two changes of direction, *c* and *d*, are rounded there is no sudden change of direction in the line of axes of the crystals and the casting retains nearly its full strength. A fillet in the corner at *a* would tend to relieve the stress. Fillets should therefore always be used in such places. If it is necessary that the finished work should have a square corner or a sharp angle, let it be made in the machine shop by cutting away the excess of metal left on the casting.

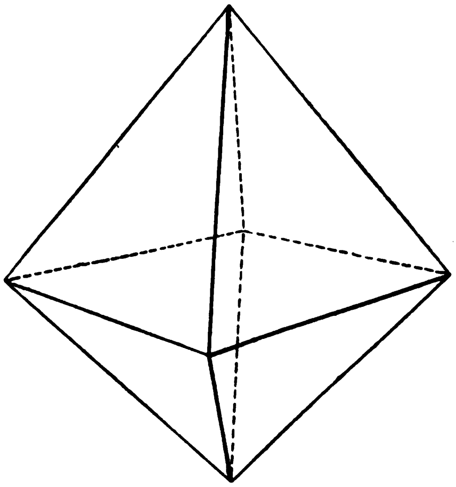


Fig. 40.

Cleaning Castings. After the castings have been poured the sand is usually shaken off from the heavier parts so as to produce an even cooling as already stated. The pouring is usually done at the close of a day's work. When the sand is shaken off, the sprues are broken from the casting by the blow of a hammer. The cleaning is done the next morning. This consists in removing the sand that may adhere to the surface of the castings, and taking the cores from the inside. There are three methods of removing the sand: by rattling, by brushing and by the sand blast. The first is used for small castings. They are put into a cylindrical shell, which is slowly revolved. The castings are thus tumbled over each other. As they rub and strike together the sand is removed and the surface of the castings made smooth and bright.

The brush is made of strong steel bristles. These remove the sand from the surface of the casting. The brushes may be used by hand or be driven by power. This is the most common method of cleaning castings.

The sand blast is used upon heavy castings. It consists of cutting off the adhering sand by a stream of sand impelled by a current of air. Care must be exercised in using the sand blast as the sand has very great abrasive power. If allowed to strike against the metal of the casting it will cut it away, and groove it deeply.

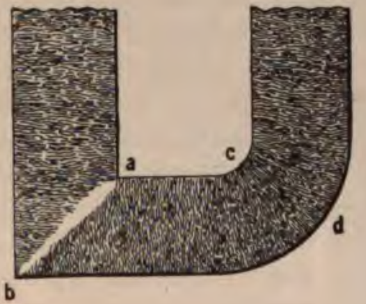


Fig. 41.

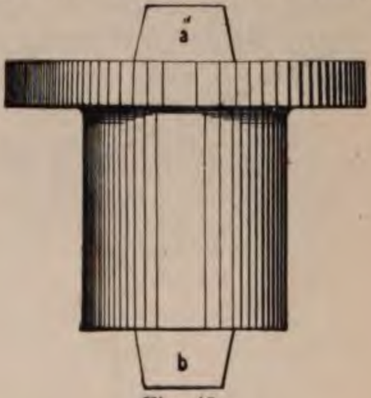


Fig. 42.

The sprues that are knocked off from the castings are usually thrown into the rattler with the shot and fine iron left in the debris from dumping the cupola. After these have been cleaned they are again thrown into the cupola and melted as scrap.

Shot is the term applied to the small pieces of metal found in the cupola dump. They are usually hard and are similar to a high grade of No. 3 iron. *Scrap* is the metal that is thrown aside and is useless except it be re-melted and re-worked.

Moulding a Gland with Core. It was stated in "Pattern Making" that a gland could be moulded so as to make its own core. This is illustrated by Fig. 23 as described in connection with Fig. 28. It may also be moulded with a vertical or a horizontal core. When moulding with a vertical core the work of ramming the drag is done in precisely the same way as when the pattern made its own core as in Fig. 23. When the drag is core in position while the iron is being poured and is cooling. When the casting is removed from the sand the chaplets will be found imbedded in the iron. The projecting parts, which were imbedded in the sand of the mould are cut off and the balance allowed to remain.

Chaplets are also made in the form of studs as shown in Fig. 48. When in this shape they simply rest upon the core or sand and are entirely imbedded in the metal of the casting. They are not adjustable. Each one is suited to a single thickness of metal. They are used where many castings of the same thickness are used. Where these thicknesses vary, the chaplet shown in Fig. 47 is usually the only one used.

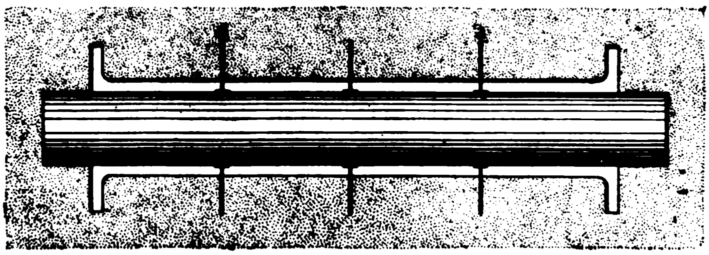


Fig. 46.

The use of rusty chaplets should always be avoided. The hot metal striking the rust decomposes it. This forms a gas that suddenly expands and is likely to cause an explosion. The result may be the destruction of the mould. The force of such an explosion may be sufficient to be felt for a distance of from six to eight feet.

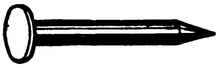


Fig. 47.

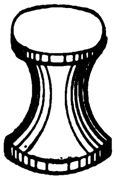


Fig. 48.

The forms of chaplets are not confined to the two shapes shown in Figs. 47 and 48. They may be of a great variety suited to the particular place in which they are to be set. They all belong, however, to one of the two types illustrated, that is, those held by being partly pushed into the sand and those resting on the cores or mould.

Gaggers. Sometimes the cope must carry a great depth of sand. In the flasks thus far described, the sand is lifted in the cope by virtue of the adhesion of its grains to each other and to the sides and bars of the cope. This adhesion to the bars of the cope may be increased by giving the whole of the interior a bath of clay water. This should always be done when there is a considerable depth of sand to be lifted. The sand may be still more firmly held by the use of *soldiers*. These are usually made of short pieces of rough pine about one-half inch square. They are dipped in clay water and arranged in rows along the face of the bars. They merely serve to increase the surface to which the sand may adhere. They are, themselves, held to the bars by the clay water which thus forms a sort of paste. When the depth of sand is too great to be thus lifted *gaggers* are used. A *gagger* is a piece of bent iron suspended at one end from the bars of the cope and carrying the sand on a projection formed at the other. Some common forms are shown in Figs. 49, 50 and 51. Fig. 49 is a simple form where the back *a* is stuck to the bar of the cope with clay water. Fig. 50 is a gagger that may be hung from the side of the cope or one side of a bar. The form shown in Fig. 51 is intended to straddle the bar and give support to the sand upon both sides.

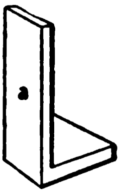


Fig. 49.

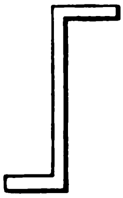


Fig. 50.

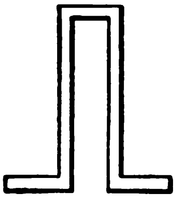


Fig. 51.

Follow Boards. In Fig. 58 of "Pattern Making" a wheel pattern was shown that could not be drawn from the sand. In Fig. 44 the round pattern is made in two parts. Where the pattern is small this is frequently undesirable. Where there are only a few pieces to be made, the method described on page 32 of "Pattern Making" may be followed. When many castings are to be poured from one pattern a follow board should be used. If the pattern is ornamented or is of complicated shape, the making of a wooden follow board is very expensive. The moulder can make a follow board very cheaply as follows: Have a frame made to fit over the frame of a cope as in Fig. 52. The frame so made to be one-half the thickness of the pattern, as in B. This is set in position beneath the cope and set on the moulding board. The cope is then rammed with sand as directed for the ordinary drag. The sand used is, however, to be especially prepared. Take ordinary new moulding sand and dry it perfectly. Then mix it with boiled linseed oil until it is nearly the same consistency or a little more soft than when mixed for moulding. Ram the cope A and frame B with this sand. Turn over and remove the frame B. Cut away all the sand remaining above the parting line C D and sleek off the surface of the same until it is made as smooth as possible. This leaves the pattern half imbedded in the sand of the cope A. Draw the pattern and finish the mould. The sand thus mixed with linseed oil will become as hard as a board. When dry it will form a perfect and serviceable follow board.

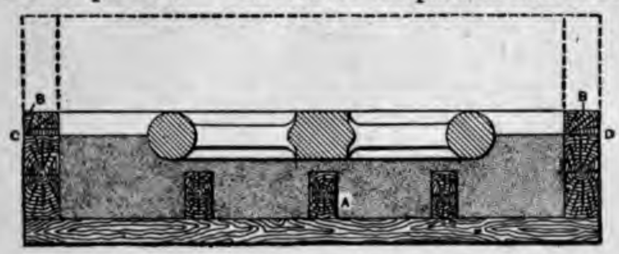
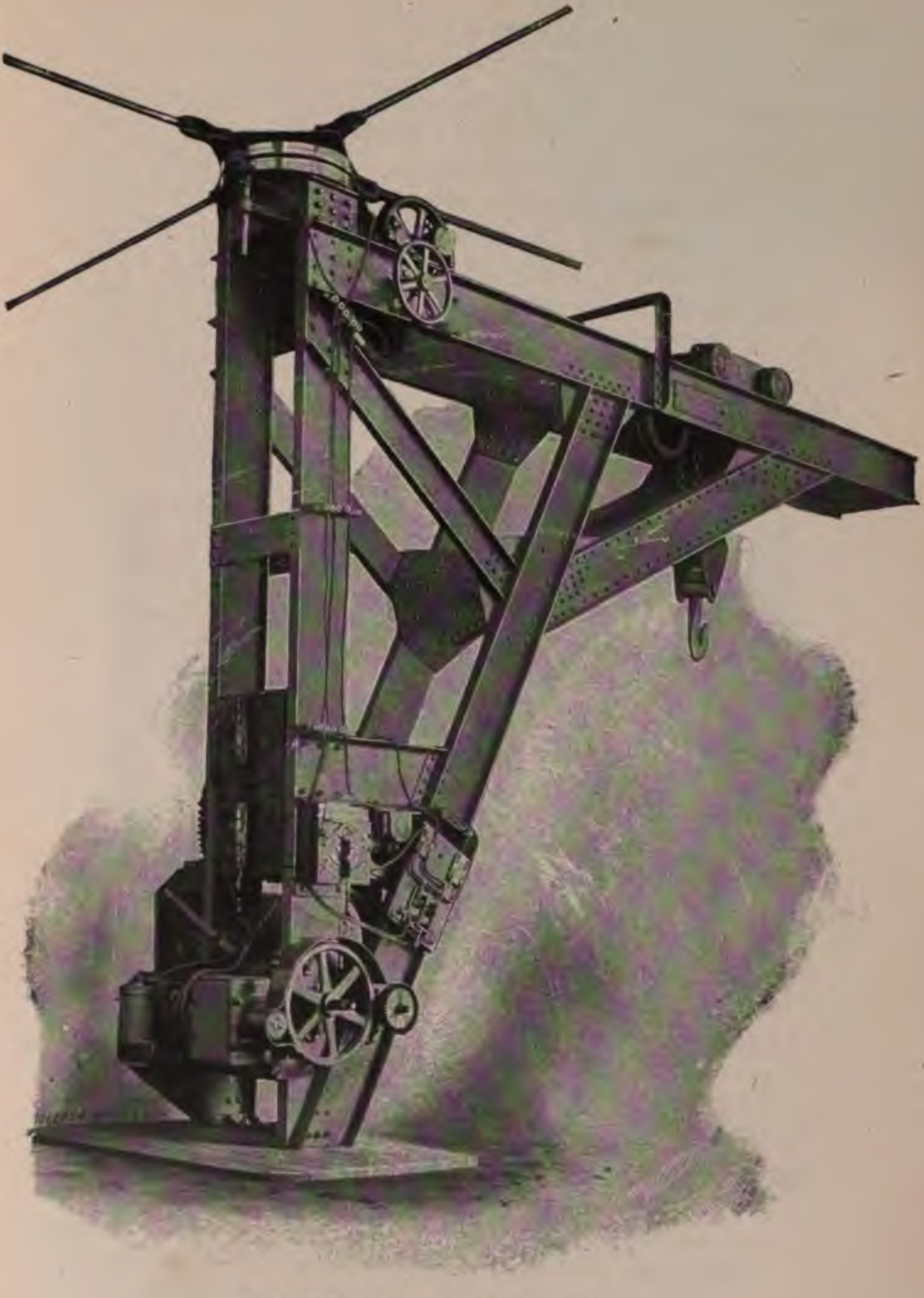


Fig. 52.

The method of using the follow board is to lay it face upward on the floor as shown in Fig. 52. Put the pattern in position and the drag upon the cope as shown. The drag, of course, rests upon the cope at the parting line C D. The frame B is not used. Ram the drag as described for ordinary work; turn the whole; remove the follow board; put on the cope and ram as in the case of simple or two-part patterns.

Three-Part Flasks. The greater portion of all moulding can be done with flasks consisting of a cope and drag as described. These are called *two-part flasks.* Sometimes, however, a casting is required of such shape that the pattern cannot be made of two pieces and drawn out of the sand of the cope and drag. When this occurs flasks of three, four or more parts are used. Fig. 53



ELECTRICALLY-OPERATED JIB CRANE.
Whiting Foundry and Equipment Co.

illustrates the use of a three-part flask for the moulding of a flanged pulley. The pattern is made in two parts separated along the dotted line E F. It is evident that it could not be drawn from the sand if rammed in a two-part flask. The parting line would then be on the line E F. The flanges would be buried in the sand and could not be drawn. The use of a three-part flask makes the moulding possible. One half the pattern C′ E F D′ is laid upon the moulding board. The drag is set over it but raised by a frame the height D G. The sand is then rammed and the drag turned. The frame used for raising the drag is removed and the sand cut away and sleeked down to the parting lines C C′ and D D′. The middle section or *cheek* of the flask A C, B D is then put on the drag, the other half of the pattern set on its mate and the sand rammed outside the pattern in the spaces *a a*. This sand is sleeked off on the parting lines A A′ and B B′. The cope is then put on and rammed. The sand of the cope fills in the hollow *b b* on top of the pattern. The cope is then lifted off leaving the pattern in the sand. In drawing the pattern its upper half is first drawn out of the sand of the middle section; the middle section or *cheek* is then lifted from the pattern, and the bottom half is finally drawn from the sand of the drag. In lifting the middle section from the pattern, the latter should be gently rapped. Other and more complicated patterns may require the use of flasks of a greater number of parts,

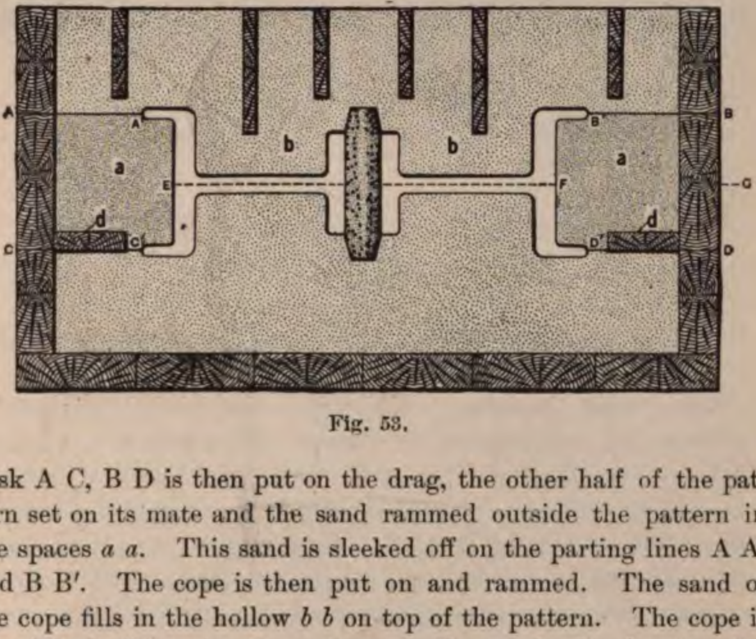


Fig. 53.

but the principle upon which they are made and used is the same as that here given. The middle sections are provided with bars in the same way as the cope or better with the lifting plates *d d.* Usually flasks are especially fitted for this work. The bars should be so arranged as to conform to the contour of the pattern in order that the sand may be firmly held. Gaggers should always be used where needed.

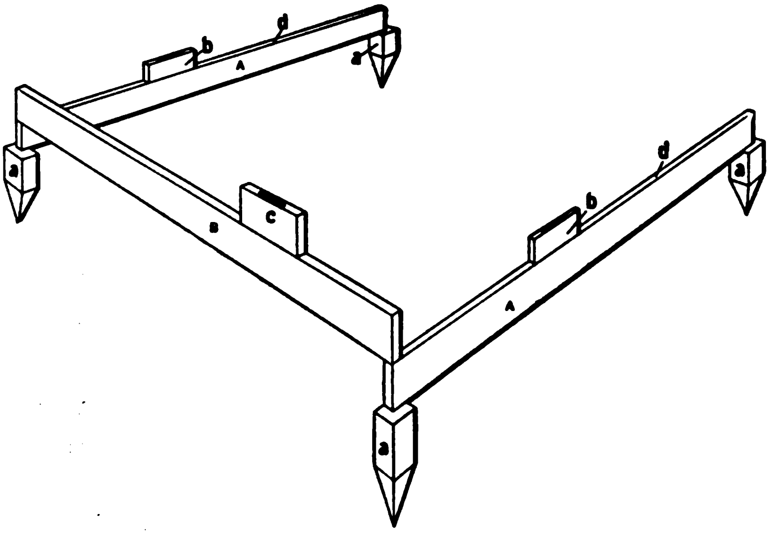


Fig. 54.

Open Sand Moulding. While it is the general practice to use flasks and patterns for the purpose of making moulds, it is sometimes possible to do the work without either or with only one. Where flasks are not used the mould is prepared in the sand forming the floor of the foundry. This work is usually confined to flat plates where the upper surface is large and smooth. As an example of this class of work, take a rubbing plate 6 feet square and 6 inches thick. This will weigh a little more than four tons. A place on the floor is selected that can be reached by a crane. The floor is first rammed hard and evenly over a surface of about 8½ feet square. The ramming is done at a level of about 6 inches below the floor surface in a hole excavated for the purpose. The bed must then be leveled over its whole area. This is done by setting straight edges in the sand 8 feet apart. The straight edges are to be set perfectly level and of the same height. It is done with a spirit level as shown. The four stakes *a a a a* (Fig. 54) are driven into the ground at the proper distances as shown. Upon these the straight edges A A are leveled by spirit levels *b b*. They are, in turn, brought to the same height by the spirit level set on the straight edge B. When the two upper edges *d d* of the straight edges A A are adjusted, the floor is scraped off with the straight edge B. It is then sleeked smooth and the pattern laid on the same.

In this case the pattern may be a square frame as shown in Fig. 55. The sand is then rammed about the outside of the pattern. the gates cut and the pattern drawn. This leaves an open mould as shown in Fig. 56. In pouring, the metal must not be run directly into the mould. The fall from the ladle would cut away the sand. It is therefore poured into basins and allowed to flow into the mould through the gates *a a* cut in the sand at the sides.

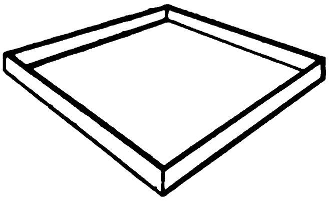


Fig. 55.

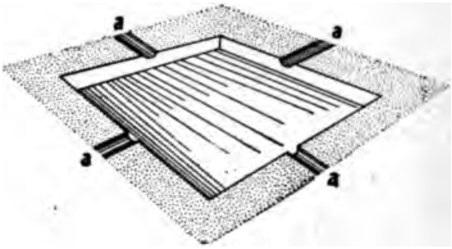


Fig. 56.

Dry Sand Moulding is frequently done in connection with green sand. It is employed where a casting is of a complicated design. The method pursued is to make a partial pattern with a core print; then make a flask to fit this print and in it mould the balance of the pattern, using dry instead of green sand. This mould is then baked in the same manner as an ordinary core which is set in the print formed by the main pattern.

Sometimes the whole mould is made of dry sand. This is frequently done in the case of cylinders for steam engines. Let us consider such an example. The cylinder to be moulded is shown in side and end elevation in Fig. 57. The method of moulding is shown in Fig. 58. The actual moulding is very similar to that of green sand work. The pattern is made in two parts. The part including the steam chest is moulded in the drag. It has core prints to correspond to the cores *a a*. These cores are made in a special box which forms at the same time the flange of the steam chest. This half of the cylinder pattern also has core prints *b*, *b*, *c* for the port cores. The pattern is moulded in the ordinary way; first the drag and then the cope. The cores *a a* and those for the steam and exhaust ports are made and dried as explained in "Pattern Making," page 56. As the core *a a* has an overhang which forms the flange of the steam chest and as that overhang is subjected to the upward pressure of metal, it is tied to the main body of the core by double headed chaplets *f f*. The cores *d d* and *g*, forming the ports are also subjected to an upward pressure. They are, therefore, held down by bolts passing through the drag and plates on the bottom. As the cores *d d* are light and easily displaced by the flow of metal, they are held firmly against the center core by the chaplets *e e*. In this case the center core *h* is carried out through the side of the flask. This assists in carrying off the gases that are formed as it is not a solid core but is built upon a pipe as will be described later. This pipe has numerous holes so that it forms a flue in the center of the mass for the escape of gas. In making large dry sand moulds of this sort, the sand is well vented before being dried. Sometimes short lengths of perforated pipe are built into the sand to facilitate this escape. The cope is rammed and set on the drag as in green sand, except that it is dried before being used.

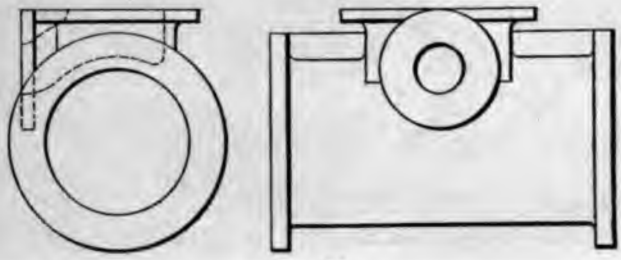


Fig. 57.

Shrink Heads or Risers. In making large castings shrink heads are put on the cope. These are in the form of gates and large pouring basins. When the mould is filled, the iron rises in these basins and forms a reserve. From this reserve metal is drawn to keep the mould filled as the metal shrinks away from its sides in cooling. It is necessary that the basin or riser shall be connected with the main body of the casting by a narrow neck, which may easily be broken away, without injury to the casting. As this neck will solidify before the heavier parts in the mould or the body of metal in the basin above, *feeding* is necessary. Feeding is accomplished by working an iron rod up and down through the neck while the metal is hardening. The method of doing this is shown in Fig. 59. In this figure *a* is the riser, *b* the mould; the rod is worked up and down in the neck connecting the two. When this is not done the upper portion of the casting is apt to be spongy and unsound.

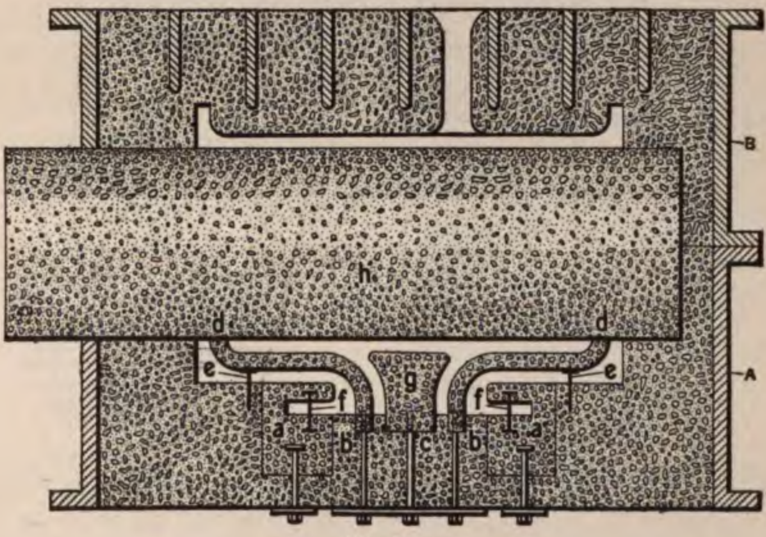


Fig. 58.

Risers are also used for *pressure feeding*. To accomplish this comparatively small gates for filling the mould are used. These gates solidify as soon as the mould is filled. The risers which are placed on the heavy portion of the mould are then filled with metal. These have a head or depth of metal considerably greater than that of the original gate. By having two such risers and pouring the metal into them alternately, that in the mould is kept in circulation for the longest time possible.

Core for Cylinder Jacket. The making and holding of the core that forms the steam jacket of a cylinder is an operation requiring great care. It can be made of loam or dry sand. It must be made about a cage, formed of rods and pipes. The jacket is usually cast with one end closed and four vent holes at the other. The diameter of the vent holes is equal to the thickness of the core. They are spaced at equal distances about the circle. The cage may be made by casting the rods and pipes inside of rings. The easiest method of casting the rings is to set the pipes and rods in an open sand mould and pour the metal around them as in Fig. 60. Reverse for the other end. The cage as finally made is shown in Fig. 61. The pipes are to be perforated for the escape of the gases. The dry sand is built about this cage covering rings, pipes and rods with the exception of one end of the pipes. These project from the core. The core, as thus made, is a hollow cylinder whose diameter and length corresponds to that of the jacket. This core is held in position by studs and chaplets. Fig. 62 shows the method of setting the core which is shown at A. It is supported by the chaplets *a a*, which are spaced at an angle of 120° around the circumference. Therefore those supporting the core do not appear in the section. The rear end of the core is

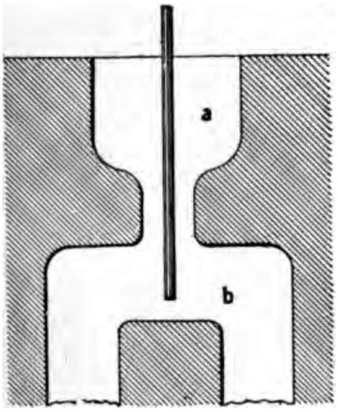


Fig. 59.

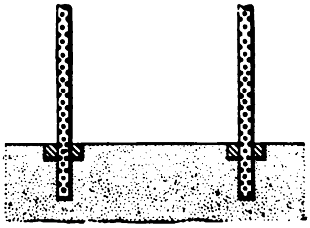


Fig. 60.

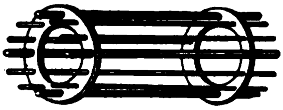


Fig. 61.

steadied by the studs *b b b*, which pass through the dry sand of the mould and are steadied by the wedges. The upper and lower wedges are reached by pockets left in the mould. The center one can be reached at the parting. At the other end the pipes are protected by the cores *d d d*. These cores also make the holes in the jacket end through which it is cleaned. The end face of the jacket mould is formed by the core *e*. This core is made in sections so that it can be placed about the rods when the core is in position and held by the studs. The method of cutting these sections is shown in Fig. 63. The mould is now ready for pouring. When the metal is cooled the cage of the jacket core will remain inside the casting. It is removed by inserting a cold chisel through the vent holes, breaking the rings into small pieces and withdrawing them through the holes. The rods are buried in the sand of the core which must, of course, be removed before any of the iron work can be taken out.

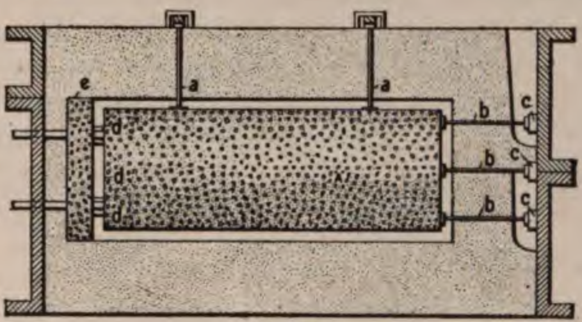


Fig. 62.

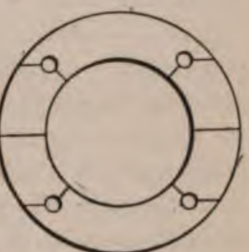


Fig. 63.

Moulding Square Columns. Square columns used in structural work are now common products of most foundries. They are invariably hollow. The exterior is usually plain though sometimes ornamented with simple devices, such as panels. The cores may be a combination of dry and green sand or dry sand alone according to the character of the work. They are of the combination type when there are holes through the side, where the green sand may be supported. They are of dry sand when the sides of the casting are solid and the core can be supported at the ends only. The first type of column is shown in Fig. 65, and the second in Fig. 64. Where there are holes as shown in Fig. 65, the core is rammed in position. The pattern may consist of a hollow square box of any convenient length, provided only that it is longer than the column to be made. The flanges may be fastened to the pattern at the points which limit the length of the casting. These flanges should be thick enough to provide both for the thickness of the metal in the casting and the core prints. First ram and level the bed on which to lay the pattern. Then put on the drag, which is formed of loose sides and ends, held by cross bars. It must be long enough to hold the casting, but may permit the pattern to project through the ends. Ram the sides between the pattern and drag. Then set on the cope and ram that. For convenience of adjustment the cope had best be hinged to the drag. Turn back the cope and draw the pattern. Now place "false" side pieces in the mould. These are merely boards with drawing strips let into them and reaching to the top of the core. Their thickness is equal to that of the casting. Now place the false core bottom in the mould. This consists of a set of rectangular dry sand cores with projections on the under sides corresponding to the holes *a a* in the side of the casting. Next set the core bar in position. This is best made of a light I beam with holes drilled through the web. It should occupy the position in

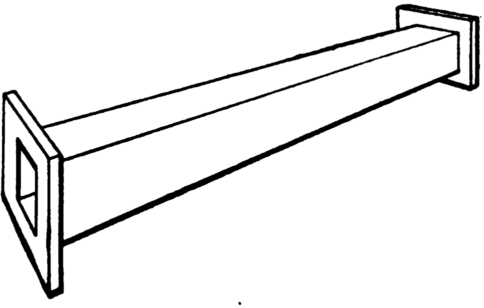


Fig. 64.

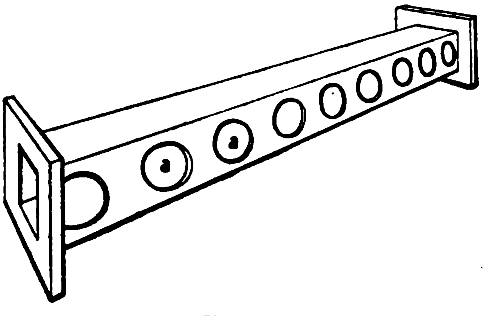


Fig. 65.

the mould as shown in Fig. 66. The I beam extends beyond the limits of the cope and is held down by driving wedges between the top flange and the end bars of the cope. Before this is done the core is rammed with green sand. The vent wires *a a a a* are laid in. If the core is much wider than the flanges of the I beams, bars *b b* are put through the holes in the web to hold down the sand. When the core has been rammed it is swept and sleeked down flush with the top of the false side pieces which rise to the points *c c* as indicated by the dotted lines. When this is done the false side pieces are withdrawn, the cope lowered to position and the I beam wedged down as directed. The metal, when poured, meets a core of dry sand *d* at the bottom of the mould with green sand above.

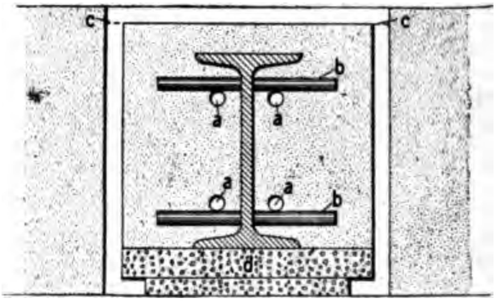


Fig. 66.

When the four sides of the casting are to be solid as shown in Fig. 64 dry sand or loam cores are ordinarily used. These are made over hollow iron cores which are coated with dry sand or loam. The iron cores are perforated with a large number of holes, which permit the gases formed to escape through the interior.

Moulding Round Columns. Round columns are usually moulded from a split pattern which is constructed as described in connection with Fig. 66 of "Pattern Making." The pattern is made of the maximum length of column to be cast. Loose flanges are used to limit the length of the pattern. The cope and drag have semi-circular holes or spaces cut out of their respective connecting edges to allow the excess length of pattern to project beyond them. As round columns are almost always solid in the shell, dry sand or loam cores are used. These cores are built about a perforated iron pipe which serves to carry off the gases.

Gear Moulding may be done from either full or partial patterns. When done with full patterns, the work is identical with that of the simpler castings that have been so fully described. They are laid on the moulding board and the drag and cope rammed in the regular sequence.

Gear Moulding with Partial Patterns. Owing to the great expense attendant upon the making of large gear patterns, such work is usually done with sectional or partial patterns. These usually consist of a section of the rim to which a limited number of teeth are attached. This pattern is placed in successive positions about the mould and the teeth rammed separately. It is held by a spindle set and held vertically at the center of the mould.

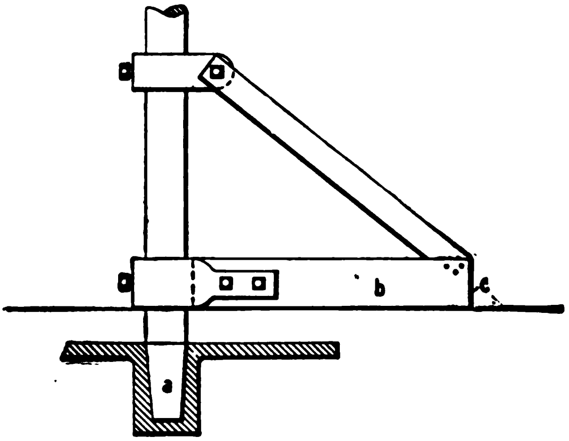


Fig. 67.

This spindle is turned to any convenient diameter and is provided with two sleeves that slide freely over it and to which the pattern is attached. For moulding a spur gear the pattern should have three or more teeth whose length is equal to those of the casting. The spindle is set in a step as shown at *a*, Fig. 67. This step must be of sufficient length to hold the spindle in a vertical position. The length depends upon the overhang of the arm *b*. The arm consists of a board bolted to one of the sleeves fitting over the spindle and braced to the other. The step is set in the sand of the floor and is held by radial arms. It must be sunk to a depth of from 6 to 12 inches more than the length of the tooth. This depth is dependent upon the weight of the gear to be moulded. The sand is then rammed into a hard bed and the floor swept off level with the sweep as shown in Fig. 67. Next remove the sweep and slip a washer over the spindle. This washer must be of the same diameter as the hub and of a thickness equal to the projection of the latter beyond the rim. Set the cope in position and stake it to the floor. These stakes are to be so driven that they will serve as guides by which the cope may again be lowered to exactly the same position after the mould is completed. After the cope has been removed, dig a hole about the spindle and imbed the washer in the sand again to the proper depth in order to form the other end of the hub. This adjustment may best be made by marking the spindle when the washer is in the first position, and making the second setting by measurement The bottom bed is now swept. This is done by lowering the sweep so that its bottom comes against the upper face of the washer. This floor is swept so that it extends several inches beyond the outer ends of the teeth. The sectional pattern is now attached to the spindle. This is accomplished by having a frame which, when slipped over the spindle will set the teeth at the proper distance from the center. The pattern should be set and gently pressed down upon the bed so as to form a faint imprint in the same. Then raise and swing it around until the tooth at one end of the segment exactly corresponds and fits into the print made by the tooth at the other end. Press it down upon the bed again and make another set of marks. Repeat the process until the entire circle has been completed. The teeth should exactly correspond and be of the same pitch without a break. If they join accurately at the end of the circle the pattern is in correct adjustment. If they do not, an error has been made and the work must be done again until the prints are uniform. When this is done the ramming may begin.

Set the pattern in the prints that have been made and ram the sand about the outside. Boards may be temporarily set in the sand to protect the ends.. When the section has been rammed draw the pattern by raising it with its attachment to the spindle and set it again in the prints beyond. Allow the rear tooth of the pattern to rest in the mould already made about the tooth previously in front. Repeat the process until all of the teeth of the circle have been made. Remove the pattern, and dress the sand forming the teeth.

The arms of such gears are usually made with dry sand cores. The pattern to which the teeth are attached should have a length that will reach from one core to another whether the teeth do or not. Raise the sweep and set the cores in position as shown in Fig. 68. Set the pattern which has the section of rim, so as to make a connection from the outer end of one core to the next. Ram the sand in between the pattern and the cores and sweep the former level with the top of the latter. Sleek this surface off and finish. Then withdraw the pattern and shift to the next section, and so continue until the mould is completed. The dry-sand cores for the arms are made in boxes and baked as already described. Now withdraw the spindle and washer and pack the hole left by

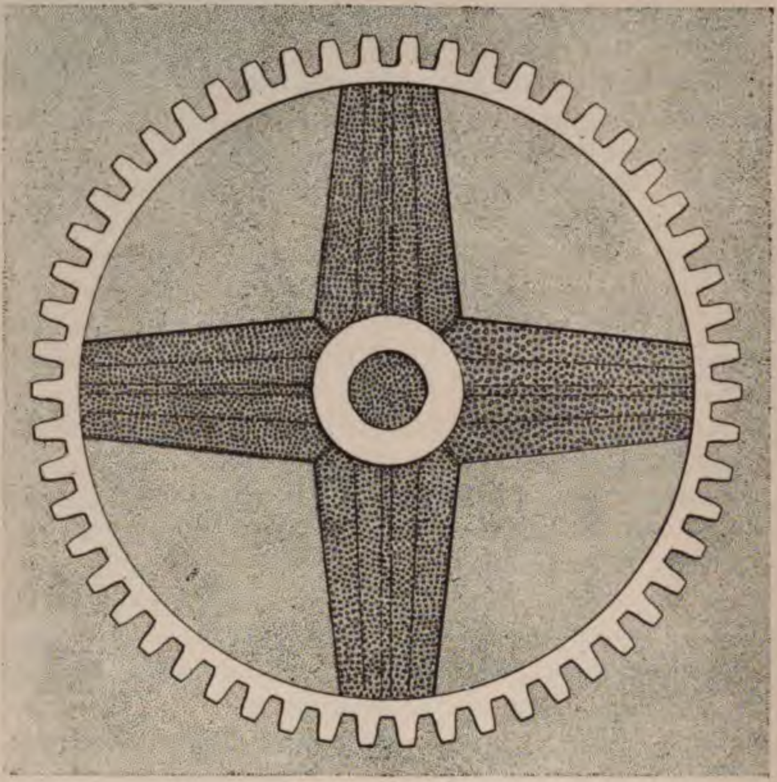


Fig. 68.

the former with green sand up to a point where it is convenient to form a rest for the center core. Set this core, and the mould is ready for the closing of the cope.

Moulding Pulleys. As already stated in "Pattern Making" on page 42, pulley patterns in a complete state are rarely used. Instead a ring, a pattern for the spokes, and loose hubs are used for making all widths of face for a given diameter. The ring is of cast iron turned smooth. It has holes drilled near the edges in which lifting hooks may be placed for drawing. If one-half the face of the pulley is to be less than the total width of the ring the latter is first set on the moulding board as for ordinary patterns.

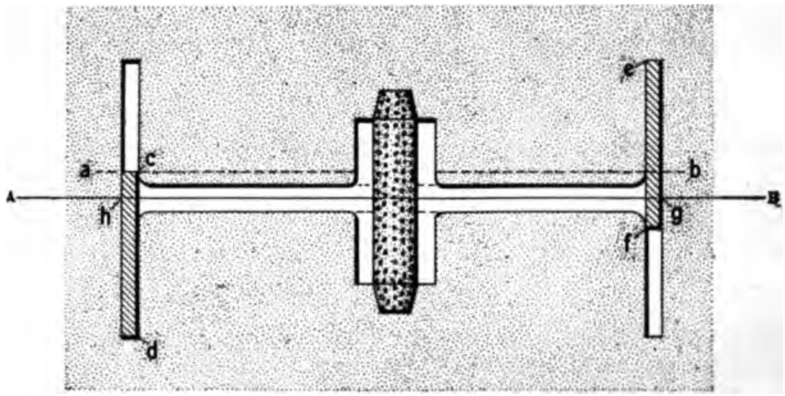


Fig. 69.

This is illustrated in Fig. 69 where the dotted line *a b* represents the face of the moulding board. The amount by which the total width of the pattern exceeds the half width of the pulley face is represented by the distance between the dotted line *a b* and the full line A B. The line A B will be the parting line between cope and drag. The drag is raised from the moulding board by a frame or wedges of this width. Ram some sand in the bottom and lay in the pattern for the spokes. This pattern is usually solid. It must be imbedded in the sand on the moulding board so that its center is exactly in line with the parting line A B. The hub with the core print is then put on and the sand of the drag rammed as in the case of any ordinary pattern. When the drag is turned the sand is cut away to the parting line. The surface of the parting line is then sleeked off. This leaves the ring projecting above the surface of the parting line by the distance *c h* as shown by the hatched section of the pattern at the left of Fig. 69. The lifting hooks are then inserted in the ring and it is drawn out of the sand of the drag until it occupies the position *e f* as shown by the hatched section on the right of Fig. 69. The friction of the sand is depended upon to hold up the ring. If the depth *f g* is insufficient to do this, the ring is not drawn to the full height at first. After raising the ring the cope is put in position and rammed as usual. Great care must be taken that the rammer does not strike the ring. Before ramming, the top section of the hub is put on.

If the ring is not drawn to its full height at *e* for the first ramming of the cope, the sand of the latter is rammed about it, and the pattern raised again. The ring is sometimes moved four or five times before the full width of the face is made. After ramming in this way, the cope is lifted off and the ring usually comes with it in the sand. The cope is turned for finishing and the ring withdrawn. The hub and spoke patterns are removed in the ordinary manner. The mould is usually filled from the hub.

In case the width of the ring is less than half the width of the pulley face, the ring is drawn up in the ramming of the drag in the same manner as already described for the cope. When the drag is turned, it is drawn in the opposite direction as stated.

When the width of the ring is greater than the total width of the pulley face there is more difficulty. The mode of procedure for the ramming of the drag is the same as in the first instance. In ramming the cope, it is placed on and rammed nearly to the top of the ring. The sand is then cut away to such a level that the ring is just embedded in cope and drag by the width of the pulley face. The ring is then drawn out of the sand. The annular hole thus left in the sand of the cope is covered by a series of flat dry sand cores. When these are set the ramming of the cope is continued. After this has been done the cope is lifted and the spoke and hub patterns removed.

Spur gears with different lengths of teeth may be moulded in this same way from but one pattern by a partial withdrawal of the pattern and successive ramming.

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Moulding Wheels. The moulding of fly-wheels may be done either with or without patterns. In case a pattern is used the work is done as already indicated for ordinary work. Where no pattern is used the sweep again comes into play. In this case, however, the outside face of the mould as well as the bed is swept. This leaves a cylindrical pit with a diameter equal to that of the wheel to be made and a depth equal to the face of the rim. The cores for the spokes are placed exactly as already described for gear wheels.

Large wheels are usually made in sections. This is done to avoid the dangers of internal stresses and the resultant cracking due to cooling. These sections may be cast from a pattern or swept as desired.

Broad faced pulleys of large diameter are also usually swept. In every instance the work may be done as already described for fly-wheels and gears.

Pipes are usually moulded on the side with a dry sand core as already described for columns. It is customary, however, in many foundries to turn the mould on end for pouring. When this is done a riser is located at the upper end into which the impurities of the iron and the washings from the core may rise as a scum. This insures a sounder casting than when cast on its side. All cast iron pipes that are to be subjected to an internal or external pressure should be cast on end.

Chilled Castings is a name applied to a class of casting wherein the metal has been suddenly cooled or chilled immediately upon pouring. The means usually adopted for chilling castings is to pour the metal against a piece of iron that forms a part of the mould. The effect of this sudden chilling is to produce great hardness on the face of the casting. The most common example of chilled castings is the cast iron car wheels that are used on all American railways. In this case the tread and flange are chilled. The *chill* is that portion of the mould which is made of iron against which the hot metal strikes. Chills for car wheels are made in several ways. The original form was a plain smooth ring that was turned to the contour of the tread and face of the flange. This ring was about 3 inches thick, in order that it might not itself become over heated. Of recent years the *contracting* chills are used. These are of various forms. One is shown in Fig. 70. In this the chilling face *a* is divided into a large number of segments which are attached to the main ring *b* by narrow necks. The object of the contracting chill is to keep the metal of the chill and the casting in contact until the latter has cooled.

The molten metal heats and expands the common chill and at the same time the cooling casting contracts or becomes smaller. The result is that the time of actual contact is very brief and the casting is likely to become imperfect in shape when cold. With the contracting chill the face *a* with its neck is heated and expanded by the molten metal. It is fastened at its outer end to the heavy solid ring *b*, which is too far away from the molten metal to become heated. As a result the face and neck are pushed toward the center by their expansion and the diameter or the chill is lessened. This type of chill, therefore, follows the shrinking casting and remains in contact with it until it is cold. Other types of contracting chills are simply plain rings of the original form, which have a stream of cold water circulated through them after the metal has been poured. Some of these are plain rings, in others the contracting necks are as in Fig. 70, with the outer ring *b*, through which the water is circulated.

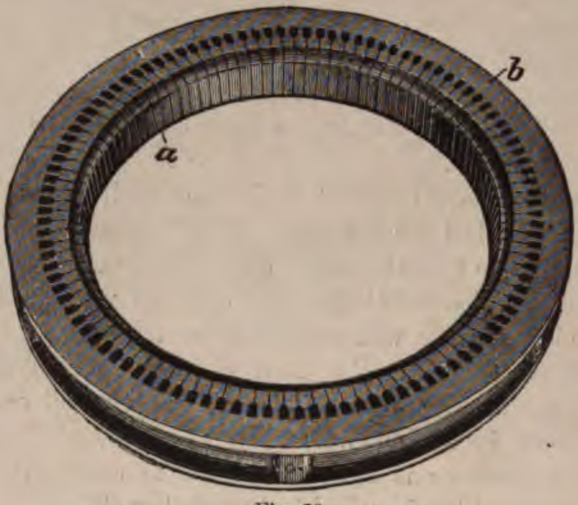
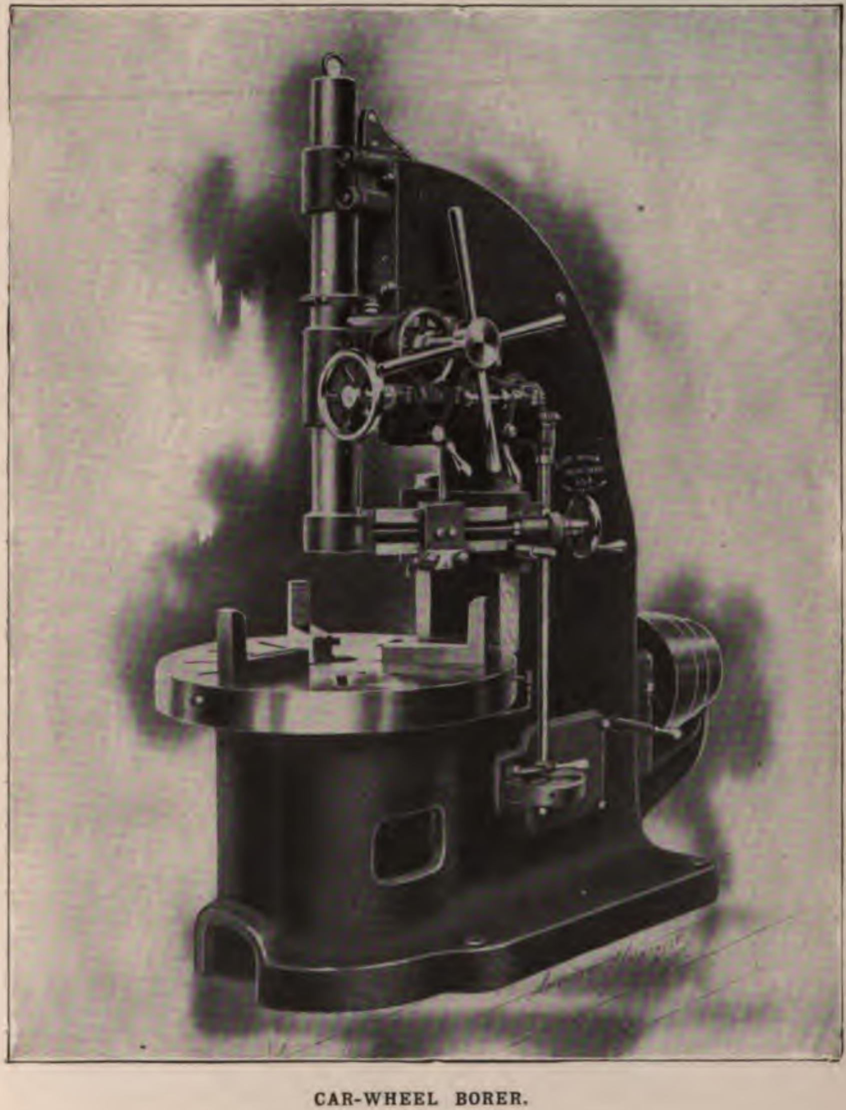


Fig. 70.



CAR-WHEEL BORER.
Baker Brothers.

The moulding of castings that are to be chilled is done in the same manner as ordinary castings. The chill is either set in position like a core or forms a part of the flask as in the case of a car wheel chill.

Chilled castings should be annealed before using. The sudden cooling of one part sets up internal stresses that will result in fracture unless relieved by annealing. The usual method of annealing car wheels is to remove the casting from the mould while it is still red hot. It is placed in a pit 7 or 8 feet deep and having a diameter a little larger than its own, with enough others to fill it. They are covered and then buried in ashes. Thus protected the wheels cool very slowly. The internal stresses are relieved because of the shape which the metal takes. This annealing usually takes about one week.

The depth of the chill, or the thickness of the exceedingly hard metal varies from $\frac{1}{16}$ to $\frac{5}{8}$ inch. It depends upon the character of the metal used, the heat at which it is poured, and the rapidity with which it is cooled. In car wheels the depth of the chill is about $\frac{3}{8}$ inch.

All irons are not suitable for the making of chilled castings. No. 1 and No. 2 iron that are rich, or comparatively so, in uncombined or graphitic carbon do not chill readily. The best chilled car wheels are made from the irons containing combined carbon. Salsbury and Lake Superior pig has, until recent years, been most extensively used for car wheel making. As these irons, especially when made in a charcoal furnace, are expensive, they are being supplanted by cheaper mixtures.

Loam. The composition and mixing of loam has already been described. Loam cores made over a perforated barrel or pipe have also been alluded to.

Loam Cores. Where the core is long and can best be supported at the ends only, loam cores are frequently used. They are also used where the core would be very large and heavy if made of dry sand. The advantages possessed by loam cores are that they are lighter, more cheaply made and offer better facilities for the escape of the gases than do the solid cores of dry sand. The method of making loam cores is very simple. A piece of pipe about three inches smaller in diameter than the outside diameter of the core is selected to form the center. This pipe is perforated by a large number of holes. If the pipe is more than three or four inches in diameter, centers or trunnions are placed in the ends to serve as bearings. This pipe is then arranged to revolve freely as shown in Fig. 71. A crank handle is attached to the pipe by which it is turned. The pipe is first wound with hay rope having a diameter of from $\frac{3}{4}$ to 1 inch. Where only a small amount of hay rope is used it is either bought ready-made or is twisted by hand. In foundries where large quantities are used the rope is made in machines built especially for the purpose. The rope should be made of long wisps and tightly twisted. It is laid on the pipe by fastening with a wire at one end and winding tightly to the other end where it is fastened in a similar manner. After the rope has been wound on and secured in position the loam is applied. This is done by means of an adjustable board A Fig. 71. The beveled edge of this board is set so that its distance from the center of the pipe is exactly equal to the radius of the core that is to be formed. The loam is then shoveled upon the board A and the pipe turned in the same direction as when the rope was being wound. The first coat of loam used should contain a considerable proportion of clay. This will make it tough and adhesive. The first coat must be well rubbed in and worked into all of the uneven places and

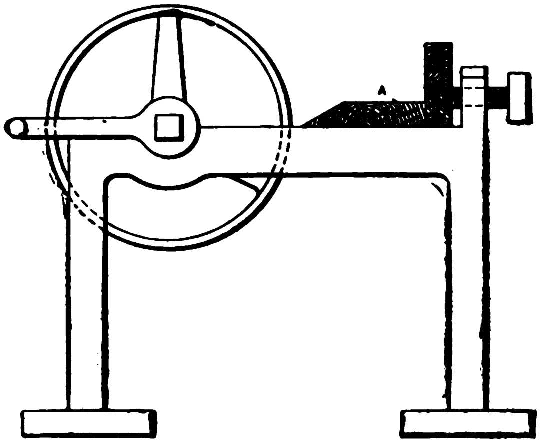


Fig. 71.

cavities. If this is not done the casting will be rough and lumpy. This work is done by hand as the barrel is being slowly turned. Too much care cannot be taken in this portion of the work. After the rope has been covered and the loam pressed into it as firmly as possible, take a small iron bar, $\frac{5}{8}$ or $\frac{1}{2}$ inch in diameter and press against the joints between the ropes, turning the barrel and working from end to end. When this is done, work in more loam and then press the whole down firmly with a block of wood while the pipe is being slowly turned. The second coat of loam which should be of such thickness as to leave about $\frac{3}{8}$ inch for the finishing coat is then put on. The second coat should be made very stiff. Unless this is done it will bag and make an uneven core. Sometimes it is advisable to so adjust the sweep board A that a smooth surface is given to the second coat. This facilitates the laying of the finishing coat. The barrel is usually placed in the oven and baked before the finishing coat is applied.

While it is still hot it should be removed from the oven and rubbed down. This is done by setting it in its bearings and pressing a brick against it, while it is being turned. This breaks the skin, roughens the surface and removes the smoke black.

The finishing coat should be put through a sieve of eight meshes to the inch and thoroughly mixed. Put enough on the sweep board A to finish the core. Before making an application of the loam, brush off the prepared surface and moisten slightly. When this has been done, let the barrel be turned slowly, and apply the loam with the hands. After one revolution make the loam thinner. The more rapidly the core is finished the better will be the results. Two revolutions of the barrel is better than a greater number. When the core has been built to size, move the loam back from the edge of the board A and then withdraw the board while the barrel is still in motion.

Rough places and lumps should be smoothed with a block of wood and not with a trowel. If the core is of large diameter, it should be turned until the loam has set in order to avoid a tendency to bag. The thickness of the loam to be put over the rope depends upon the thickness of the casting to be made around it. Castings 2 inches thick will need about 1 inch of loam. In such cases the pipe should be 4 inches smaller in diameter than the finished core. As soon as the surface of the mould has become hard enough to absorb the blacking it should be applied. The best condition of mould or core for blacking is when it is just damp enough to soak up the material, and be ready for sleeking in five or six minutes thereafter. In sleeking a loam mould, press on gently with the tools. Too great a pressure closes the pores and tends to start the blacking from the surface of the mould. The less the sleeking the better. Rough places or marks left by sleeking can be smoothed by going over the surface with thin blacking applied with a camel's hair brush. After blacking, the core is again dried in the oven, when it will be ready for use.

The object of using hay rope about the pipe is two-fold: it serves as a convenient binder for the loam and by burning or disintegrating under the influence of heat, the pipe is loosened and easily withdrawn from the casting. If the loam is too thin, the rope will be entirely burned away. When this occurs, the loam is crushed in and the iron, in contracting, is apt to so pinch the pipe that it can only be removed with difficulty.

Loam Moulds may be made without any patterns, with partial patterns and with complete patterns. The first is only used where the casting is of the simplest form. The second is the common method of making loam moulds. The third is seldom used, since a complete pattern makes it possible to mould in green or dry sand, which is cheaper than the use of loam. Loam moulds are usually built of bricks over which a coating of loam is spread. The loam, that is spread on brick work, is of the same character as that already described for loam cores. It is applied and treated in practically the same manner. Loam moulds are usually employed where the casting is large; where only one of a kind is to be made, and where it would be expensive to provide a pattern. They are also used in emergencies where the casting can be made in loam more quickly than a pattern for dry or green sand moulding could be put together. The most frequent application of loam moulding is to be found in the making of large cylinders for steam engines.

Simple Cylinders. In the moulding of a simple cylinder like that shown in Fig. 72, the casting is made with a shrink-head as shown by the dotted lines at *a*. This is to receive the dirt and washings from the mould. Loam moulds yield a greater amount of such impurities than dry or green sand. They rise to the top and the shrink-head is cut off from the finished casting, leaving sound and solid metal beneath. This form of cylinder with internal flanges is a common and simple job. The mould is formed of two parts; the core and the cope; each is swept on the same principle as the loam cores. It is first necessary to obtain a strong circular plate upon which the whole structure is to be built. This plate for a cylinder 40 inches in diameter and 60 inches long should be at least 2 inches thick. It should not be less than 60 inches in diameter and be provided with 4 projecting lugs to which the hoisting tackle may be attached. It is first placed upon a solid blocking and leveled. Through the hole in the center a spindle is run, similar to that shown in Fig. 67. This spindle should be held at the top as well as the bottom, and rise at least 2 feet above what is to be the top of the mould. It will then clear the cap and hoisting bar.

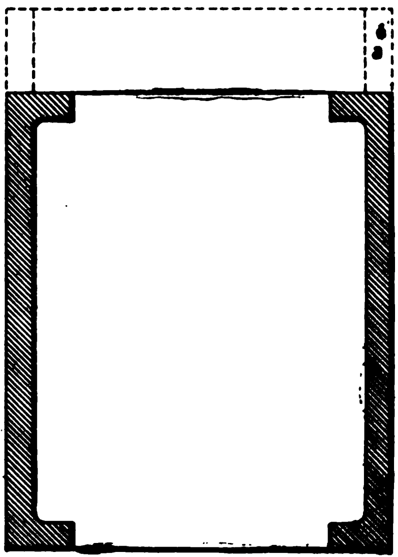


Fig. 72.

Fig. 73 shows a section of a loam mould constructed for the casting of a cylinder like that of Fig. 72. The spindle *a* is shown with its step *b*. The base ring *c* supports the whole mould. The first thing to be done is to cast the base ring *c*, the cope ring *d*, the core ring *e* and the cap ring *f*. All of these rings may be made in open sand moulds. As already noted, the base ring *c* must be large enough and heavy enough to carry the whole weight of the mould, when slings are attached to its lugs *g g*. The cope ring *d* must be of the same outside diameter as the base ring. Its inside diameter, however, should be about 2 inches larger than that of the finished cylinder. It must be strong enough to carry the cope. Lugs are also cast on the outer edge by which the cope may be lifted. The core ring *e* is simpler and may be lighter. It has to carry the overhang of the core. The cap-plate or ring *f* is cast with bars projecting downward from the under side. These serve the same purpose as the bars of an ordinary cope.

Loam moulds of the character about to be described are built up of common red brick. They are set in a mortar composed of mud made from the scrapings of the foundry floor, and are smeared on the mould side with loam.

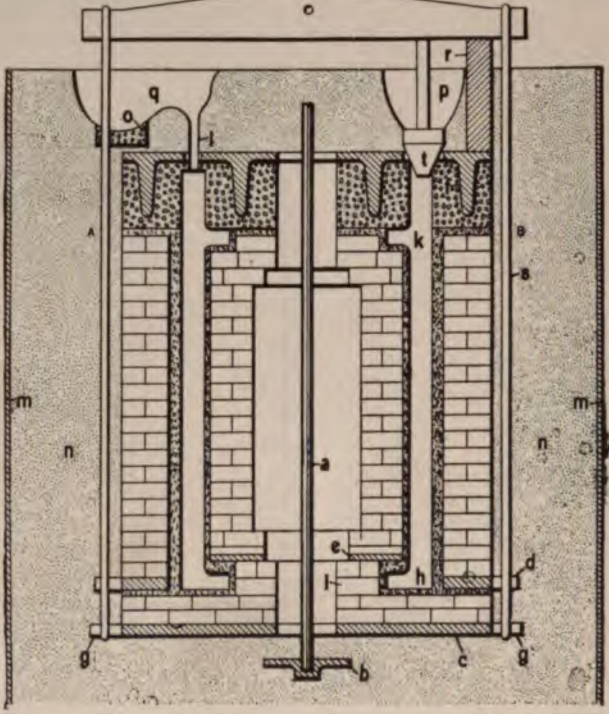


Fig. 73.

The first thing to be done in the case under consideration is to set the base plate firmly on the floor or blocks and central with the spindle. On this lay a ring formed of two courses of bricks. Set them as closely together as possible and have the spaces between them well filled with the mortar. The first sweep to be fastened to the spindle may be a plain board like that of Fig. 67. The outer edge *c* Fig. 67, swings on a radius equal to that of the cylinder to be made. Over the first layer of brick spread a layer of loam about $\frac{1}{2}$ inch thick at the outer side. Sleek this off and finish. Before proceeding it must be dried. This may be done by hanging a charcoal fire in a basket over it. On this lay the core plate *d* Fig. 73. The bricks should be carefully laid and stand off about an inch from the outer end of the sweep. After the bricks are laid the loam is to be rubbed on and swept off to the proper radius with the board. This first coating of loam will have to be partially dried by hanging a charcoal fire in front of it. The finishing coat or *skinning loam* is then applied. Skinning loam is the ordinary loam thinned with water. After the cope has been built up to the parting line A B and partially dried it is ready for the blacking. Flat brushes should always be used for this work, as they spread it more evenly than either a round brush or a swab. The blacking should be laid on to a thickness of about $\frac{1}{16}$ inch. Spread the blacking carefully and do not sleek. Where sleeking is done on the convex surface of a cope the skin of the loam is easily loosened and will be likely to scab.

After the cope has been finished marks are made on it and on the base, so that it can be replaced in the same position in which it was built. It may then be lifted off and sent to the oven for drying.

The next operation is the building up of the core. The first sweep used resembles that of Fig. 67; the second has an undercut on the outer end to form the flange *h* as shown in Fig. 74. Carry out the coating of loam on top of the base bricks and sweep smooth with the board of Fig. 67. Cover it with a layer of skinning loam. Let it harden and then throw on a sprinkling of parting sand. Change the sweep and use the one shown in Fig. 74. The flange beneath the core must be formed with sand. Use old sand and some that is well sifted and *tempered*. Tempering is the term applied to the cutting up and dampening of the sand, when it is being prepared for the use of the moulder. Pack the sand in by hand and sweep it off. Dampen it and sleek it down until it clears the sweep. Then finish it off with skinning loam. This surface must now be prepared to give an impression to the core. This can be done by swabbing off the surface with coal oil and sprinkling on some parting sand before it has dried.

The sweep used for the flange is now removed and an overhung one as shown in Fig. 75, put in its place. While working near the bottom of the core the overhanging piece *a* had best be stayed by a supplementary connection to the spindle like the bar *b* at the top. This is to be removed when the brick work has risen to that height. First lay up the brick work at *i* Fig. 73, until it has risen about 1 inch above the top of the sand flange *h*. Lay on the loam as the work progresses. Put the core plate *e* in position. This plate should have pin projections on the lower side to steady it. Proceed with the laying of the brick of the core in exactly the same manner as that pursued with the cope. Let the brickwork stand about an inch inside the sweep *a* of Fig. 75. Cover it with loam and finish in the same way as in the case of the cope. A fourth sweep must be added to sweep the upper flange *k* Fig. 73. The cope and core both end at the parting line A B. When finished and before drying, the sand forming the false flange *h* must be removed. Above this the mould may be of dry sand carried on the cap *f*. In this cap a series of holes *l* are cored through which the metal is poured. When the core is finished it is lifted by the base-plate *c* and carried to the oven.

Fig. 74.

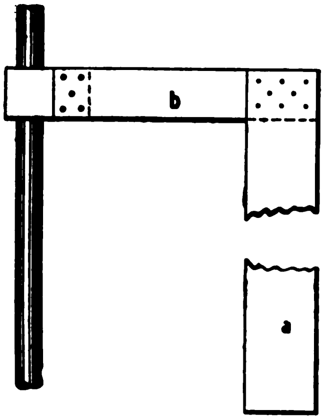


Fig. 75.

Sometimes, in the case of cores too large to be placed in the oven, the drying is done by means of charcoal fires.

After the loam work has been dried, a pit is dug in the floor for casting. It should be deep so that the ladle can be conveniently worked above the mould. Ram a level bed in the bottom of the pit to receive the base plate and lower the whole mould into position. As the outward pressure of the iron upon the cope is very great, it must be sustained in some way for the brickwork alone would have insufficient strength. The best way is to surround the mould by a boiler plate curb *m m*, and ram the intervening space *n n* with sand. If a curb cannot be obtained the pit may be dug out to the solid earth and rammed. The curb is the better method.

After lowering the mould into the pit the covering above the cover plate is made of sand. In this there is a riser *p* and a pouring basin *q*. It is well to protect the bottom of the latter with a core *o*, so as to prevent sand from being washed into the mould. When everything is in position it is well to clamp all parts together by placing a wedge *r* between the supporting bar and the cover plate. This puts a tension on the suspension rods *s* and holds all the parting surfaces in close contact.

The hole between the shrink head and the riser should be plugged with a weight *t*. This plug is to be kept in position until the iron touches it, when it should be instantly raised. The object of keeping the plug in and the riser closed is to put an air pressure on the mould. Such a pressure serves to bind all of the parts together. This course is, however, not always followed. Some moulders prefer to leave all risers open. It is well, when pouring to have a small fire of shavings in the core. The object is to rarify the air and heat the parts.

The principal precautions to be taken in loam moulding of this sort are: to have the loam well dried before pouring; to provide suitable shrink-heads and risers for the reception of the impurities that may arise; to have the brickwork well supported by sand rammed about the outside; to ram the sand harder near the bottom than at the top for it has to sustain the greater pressure at the former point; and to be sure that all dimensions of the mould are accurate.

In case of very large castings the moulds are frequently built in the pit and dried in position by charcoal fires.

Engine Cylinder. One of the most common jobs of moulding that is done in loam is that of large engine cylinders. In this work partial patterns are usually provided. These patterns ordinarily consist of the core boxes for the ports and adjacent parts. The core and the cope are built in a manner similar to that described for the simple cylinder with internal flanges. Fig. 76 illustrates a vertical section of the mould of a steam cylinder. In this case the flanges are upon the outside of the cylinder. Here they serve to hold the studs for bolting on the cylinder heads. In the building up of the cope, a plate *a* is built into the brickwork to carry what now becomes an overhang of the cope instead of an overhang of the core as in the previous example. This plate is of the form shown in Fig. 77. A part is cut away at *a* Fig. 77, to permit of the placing of the pattern which is to form the print for the core which forms the steam passages and ports. This plate should be seated on the lower layer of bricks as already described for the simple cylinder. In general the use of a pattern in con-

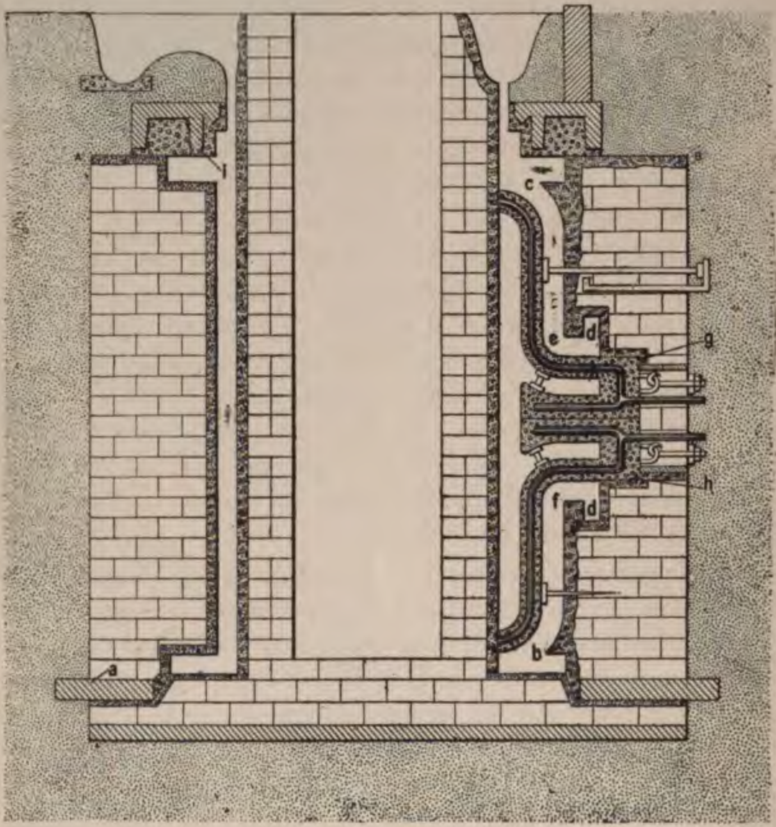


Fig. 76.

nection with loam moulding is troublesome. The pattern must be well oiled in order to prevent the loam from sticking to it. After the pattern is withdrawn the mould must be well washed. If all of the oil is not washed from the loam the finishing coat will not stick to it and the mould will be apt to scab. For these reasons some moulders prefer to build the loam for the core prints from drawings. Where a pattern is used, as in Fig. 76, it should reach from the point *b* to the point *c*. The overhung flanges of the steam chest at *d d* are made in loose pieces that are left in the mould when the main pattern is withdrawn and are themselves removed afterward. The pattern should be made so as to present a surface for the outer surface of the steam passages from *c* to *e* and from *b* to *f*. It also carries a core print extending back into the brickwork to the points *g* and *h*. This pattern should be accurately set when work is commenced on the cope. Measure up from the lower end of the cylinder to the center. Fix the center of the pattern at that point. Hold the pattern in position by props and stays so arranged as not to interfere with the progress of the brickwork. Oil the face of the pattern, which is to come in contact with the loam, with coal oil and build the brick work around it. Let the bricks be about an inch from the pattern and fill the intervening space with a stiff loam. At the center, opposite the location of the ports, pipes should be built into the brickwork. These pipes serve the twofold purpose of permitting the admission of bolts to hold the cores in position and of providing a means of escape for the generated gases. After the brickwork has been carried up to the parting line A B the pattern is withdrawn. Carefully wash away all of the oil that may adhere to the surface of the loam. Then apply a coat of skinning loam as directed for the simple cylinder. After this the mould is to be blackened and dried as before. The cap-plate *i* does not differ essentially from the one that has already been described. Above the cap-plate are placed the pouring basins and runners as before. The mould is

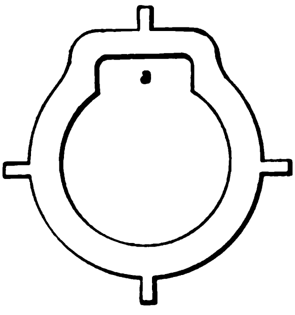


Fig. 77.

strengthened by ramming sand about the outside as in the case of the simple cylinder.

Loam moulding is extensively used for large castings where only a few, possibly but one of a kind are to be made, and where complete patterns would be expensive. It is also a convenient method of making large complicated castings where, if they were to be moulded in green or dry sand, three, four or five-part flasks would be required. Other instances of a common use of loam moulding are to be found in screw propellers, kettles, condensers and the like.

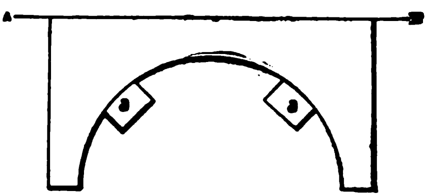
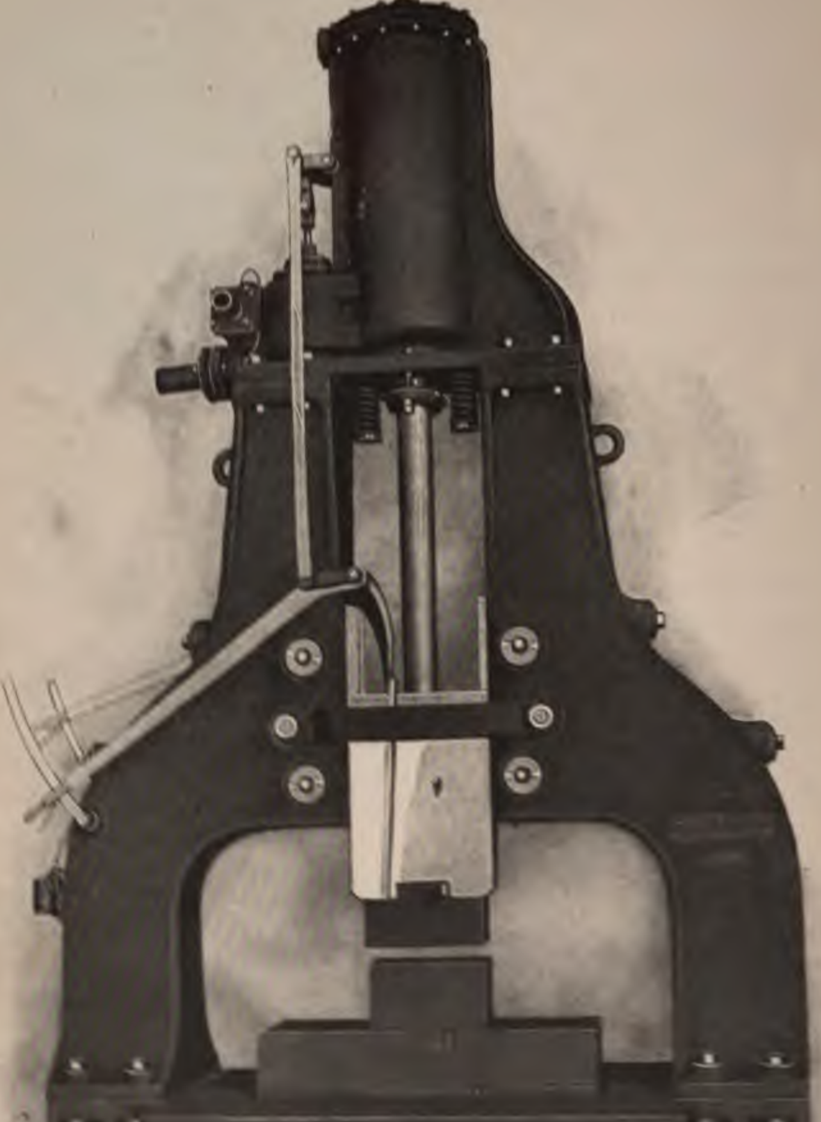


Fig. 78.

Loose Pieces. In the description of the moulding of the last example, a reference was made to loose pieces on the pattern that do not draw out of the sand with the main body. Loose pieces are used where it is desired to avoid the placing of a core or where core prints are to be made. Thus in Fig. 78, if the pattern were imbedded in the sand of the drag with a parting line at A B, it could not be withdrawn unless the pieces *a a* remained in the sand. These pieces are therefore made loose and then drawn out on the angle at which they are set after the main pattern has been removed from the sand.



5,000-POUND BEMENT DOUBLE-FRAME STEAM HAMMER.
Niles-Bement-Pond Company.

FORGING.

The art of forging is one of the oldest in the history of man. As already noted in "Foundry Work," while the art of smelting must have preceded that of forging, the latter antedated by many centuries that of making castings of iron. It is probable that in the early years the metal was rare and costly. Its being used for personal adornment seems to prove this. Such examples are the iron finger rings found in the tombs of the ancient Egyptians. Comparatively few specimens of ancient wrought iron work have been discovered however. This is due to the fact that it rusts so readily. Gold, silver and bronze, on the other hand, do not corrode rapidly. According to Pliny the best steel used by the Romans was imported from China, where iron is said to have been worked as early as 2000 B. C. During the Middle Ages iron working reached a high state of development in Europe. This is shown in the beautiful designs of wrought iron found in the churches and palaces of the time. Hinges, brackets, balconies, knockers, grills, armor and weapons were executed of the most intricate and artistic designs. The entrance door of the Hall of Merton College, Oxford (shown in Fig. 1), is an example of this work.

Although this work was beautiful and delicate, it was all light and could be made by hand. The forging of the heavy frames and shafts that we have to-day would have been impossible with the appliances then available. The steam engine makes present forgings possible.

The work of the smith became changed somewhat when the art of making castings was discovered. From this time on, the delicate, intricate designs were made by casting and the smith devoted himself to making forgings of strength rather than beauty. As the demand for artistic forgings decreased, that for mechanisms increased until to-day artistically hammered work is counted among

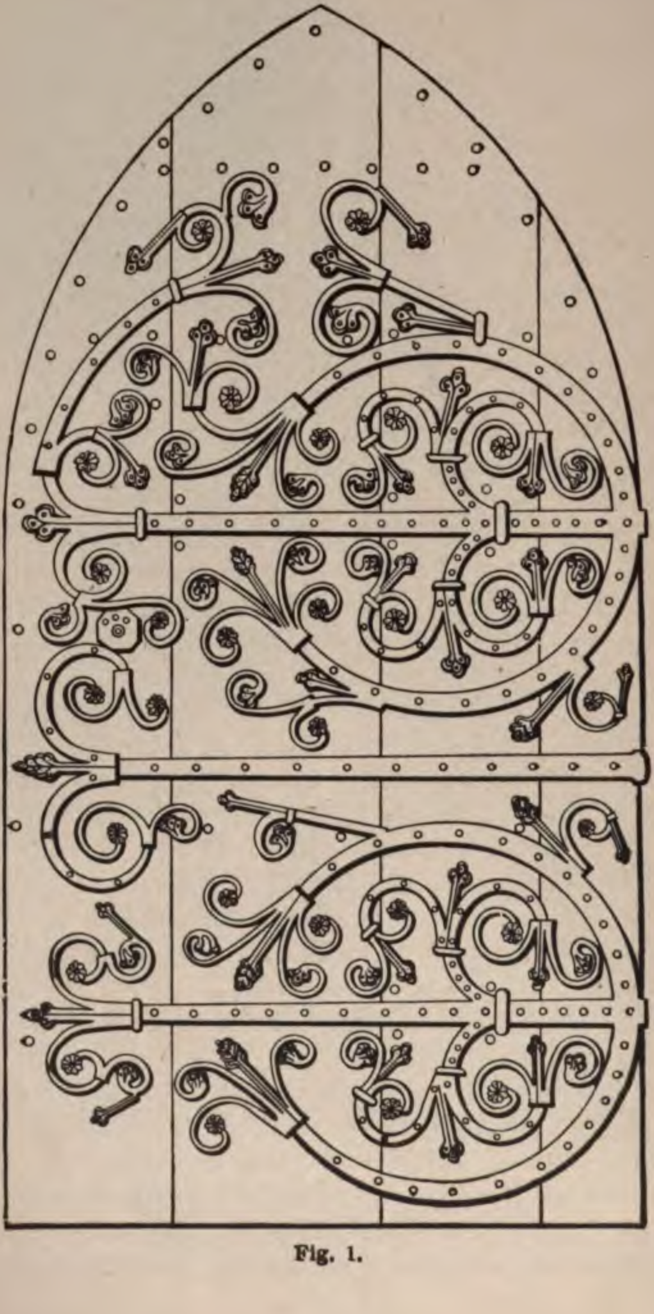
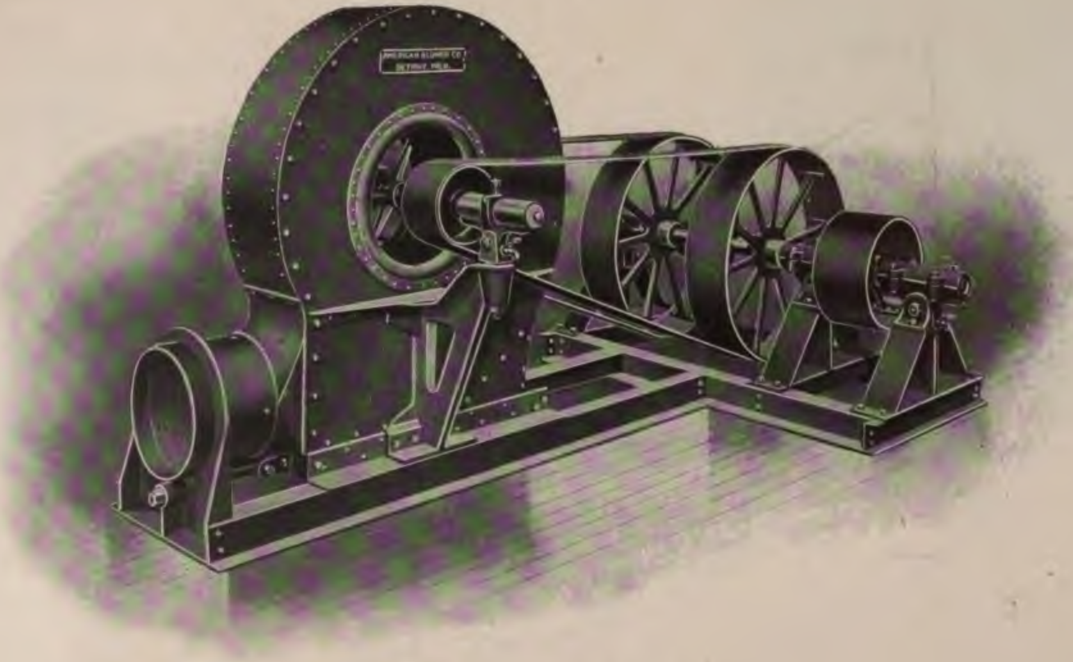


Fig. 1.



STEEL PRESSURE BLOWER.
American Blower Company.

the luxuries of the few. The products of the forge find application in all grades of modern mechanisms, from a lady's watch to armor of a modern battleship.

The Materials upon which the work of forging or blacksmithing is done, are wrought iron and steel. As explained in "Metallurgy," wrought iron is an iron from which "the silicon, phosphorus and most of the carbon has been removed." Steel usually contains some of the impurities that are characteristic of cast iron with the marked peculiarity of holding a varying percentage of carbon. Mild steels are so-called on account of the small amount of carbon which they contain. As the percentage of carbon increases, it becomes more difficult to weld the metal. Greater care must also be used in heating lest the metal be burned and its strength destroyed. Until recently all heavy forgings involving welding, were made of wrought iron, but new processes have made it possible to weld steel. It is now possible to procure heavy steel castings that may be bent, twisted and when broken, can be welded.

The properties which it is necessary for a metal to possess for forging are ductility and malleability. Many of the steels are not welded but are hammered into shape from a single original piece. The various kinds of steel are described in "Metallurgy."

The Shop may vary in size from the small blacksmith shop with a single forge to the great establishment fitted with ponderous steam and power hammers and innumerable fires and furnaces. There are, however, a few common characteristics of all such shops. The floor should be of earth or cinders. The ground beneath should be well drained. A good method of laying a floor is to excavate to the depth of about 18 inches and fill in 12 inches of this with broken stone. Cover with a layer of finer stone and use earth for the top. This makes a macadamized floor. If the shop is connected with a machine shop, the floor can be still further improved by covering to a depth of ½ inch or so with cast iron chips. When these have been wet a number of times they rust together and form a hard even surface.

The walls of the building are preferably of brick. The roof may be of wood or iron, with a slate covering. It should also contain a monitor ventilator along the ridge pole through which smoke and gases may escape. If iron work is used in the construction of the roof, it should be thoroughly protected from corrosion by an asphalt or graphite paint. The side walls should be amply supplied with windows, and the ventilation should be as complete as possible.

A distinction is usually made between a blacksmith shop and a forge shop. The difference lies in the weight of the work and the method of doing it. In the blacksmith shop, the work is usually done by hand and is heated in open fires. In the forge shop machinery is employed to do the work, which is heavier, and the heating is done in a closed furnace. The difference is, therefore, one of degree and not of kind. The two classes of shops will be treated separately.

The Forge. While forges or fires are of many shapes and sizes the principles of their construction remain the same. An ordinary blacksmith forge is a fireplace in the bottom of which there is a tuyere for admitting a blast of air to blow the fire. Where the air blast is furnished by a hand bellows the pipe leading therefrom to the tuyere is open throughout. Where a power-driven blower furnishes the blast, there is a valve in the pipe for regulating the same.

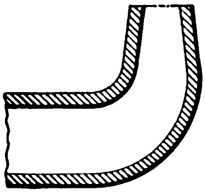


Fig. 2.

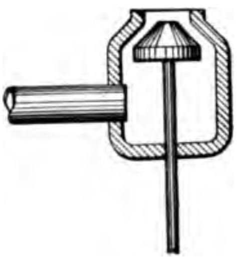


Fig. 3.

The usual form of tuyere consists of a single blast pipe, opening into the bottom of the fire pit. This may be a simple nozzle as in Fig. 2, with the blast regulated by a damper in the pipe; or, it may have a regulator at the mouth of the tuyere as in Fig. 3. Sometimes the tuyere has several openings, and is then in the form of a grate. Whatever its form, it should be possible to clean it from below, in order that coal and clinkers falling into it may be removed.

A common form of forge is shown in Fig. 4. It is built of brick and the chimney rises from one side. A bonnet (*b*) placed above the chimney opening increases its draft. The fire is at one side and only comparatively light work can be done in it. An improved form of forge is shown in Fig. 5. In this the fire is at the center. The smoke and gases are carried off through a bonnet suspended from above. With this construction it is possible to work on all sides of the fire and long bars may be heated at any point.

The Fuel used in the forges thus far described is invariably bituminous coal. It is desirable that the coal should be as free as possible from sulphur and earthy matter. Sulphur gives off choking fumes that are disagreeable and it has an injurious effect upon the iron. Earthy matter produces clinker and chokes the tuyeres. A coal that contains a great deal of gas is also undesirable. Gas distilled from coal cannot be burned in an open fire. Formerly, almost all blacksmith coal was imported. Now, however, such coal as that mined in the Cumberland region is admirably adapted to the purpose. Cumberland coal averages about the following composition:

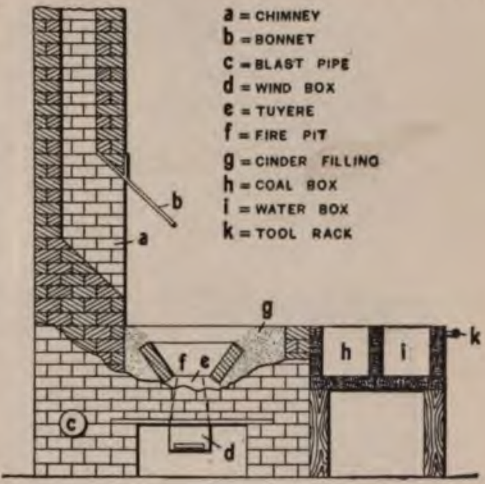


Fig. 4.

Carbon	93.81 per cent.
Hydrogen	1.82 per cent.
Oxygen	2.77 per cent.
Ash	1.60 per cent.
	100.00 per cent.

From this it will be seen that carbon stands very high and that the losses due to the distillation of hydro-carbon gases must be very low. Anthracite coal is used in special furnaces, which will be described later. Charcoal and coke are also used in limited quantities.

The Blast is furnished to the fires of a blacksmith shop by blowers of various kinds. For many years the ordinary bellows was used. This has been superseded by the fan blower which is now almost universally used, even for hand power.

Such a fan blower is shown in Fig. 6. It is formed of a thin cast iron shell in which there are a set of rapidly revolving blades. These blades set up a current of air which presses against the side of the shell and escapes through the tangential opening. The pressure of the blast used for an open blacksmith fire varies from about 2 to 7 ounces per square inch. The lower pressure is used for a light fire and light work. The higher pressure is suitable for heavy classes of work.

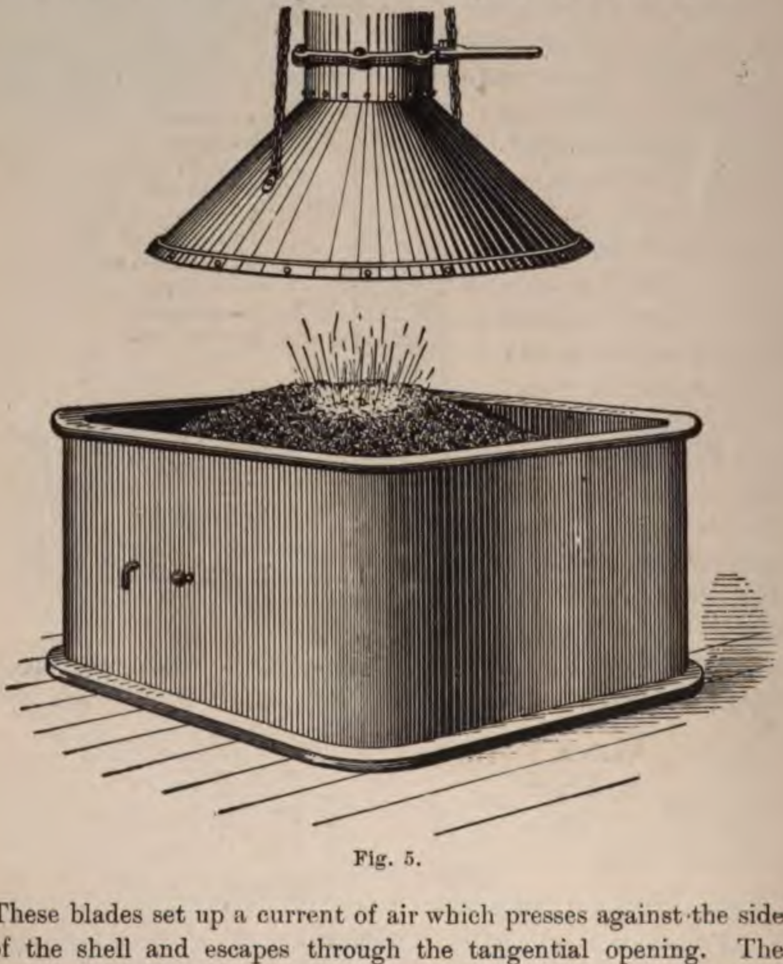


Fig. 5.

Tools. The tools used in a blacksmith shop are of the simplest description. The most important are the hammer and anvil. Then come the tongs, flatters, swages, drifts, fullers, punches, calipers, etc.

Hammers differ in weight more than in form. The common shape of hammer used is the ball pene hammer shown in Fig. 7. In weight they vary from five or six ounces to three or four pounds, and are used according to the work in hand. The effect of a blow from a hammer depends upon the weight and the speed. A heavy hammer produces a deeper effect upon the metal than a light one. The reason is that the force of a light blow is easily absorbed by the metal in the immediate vicinity of the surface.

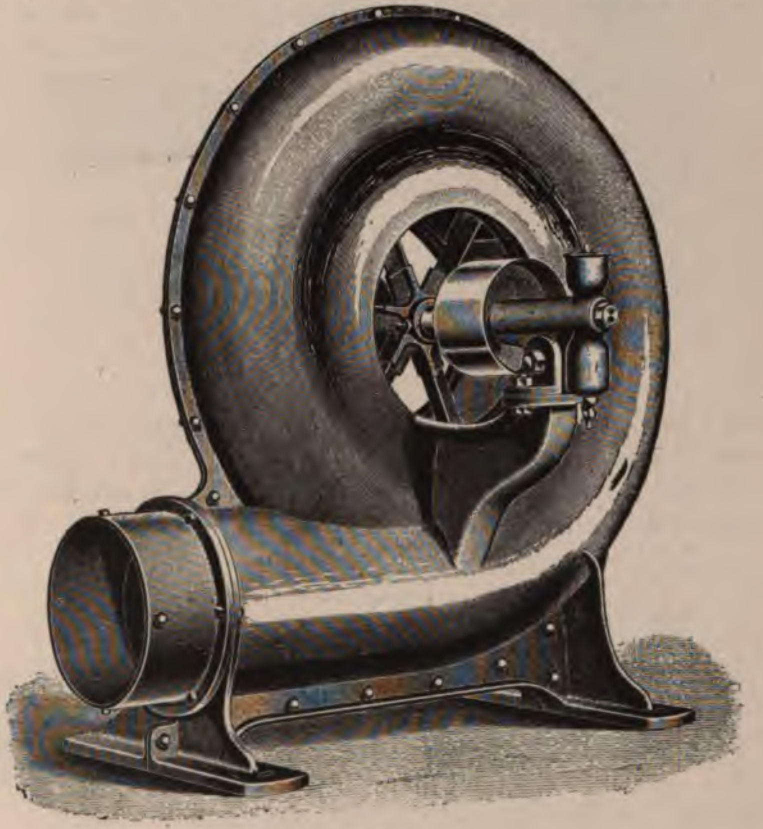


Fig. 6.

A heavy blow cannot be absorbed as readily, hence the metal shows the effect for a greater distance from the surface. This is illustrated by the rivets shown in Figs. 8 and 9. In Fig. 8 the metal at the end of the rivet is turned over by blows from a light hammer. In Fig. 9 where a blow was struck by a heavy hammer, the metal is upset for nearly the whole length of the rivet. There is no sudden enlargement at the end, but an increase in size for some distance there-from.

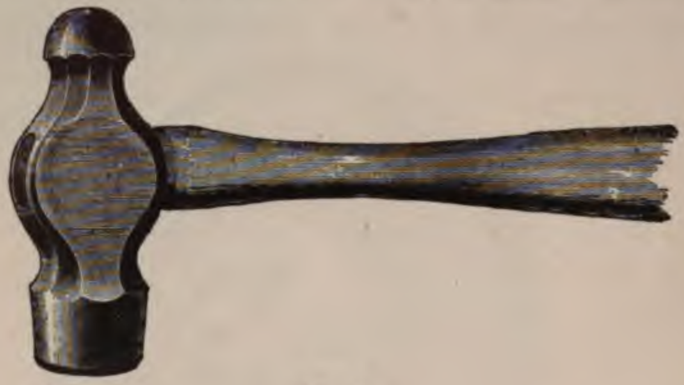


Fig. 7.

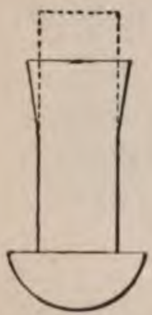


Fig. 8.

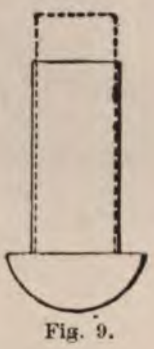


Fig. 9.

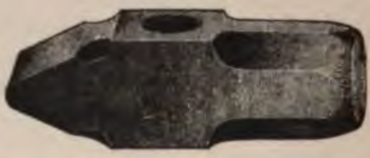


Fig. 10.

Another form of hammer is shown in Fig. 10. This is the sledge hammer, and is used for striking heavier blows than can be given with the ball pene hammer of Fig. 7. The peen of this hammer is straight and rounded on the edge. Such hammers weigh from five to twenty pounds.

In the fitting of the handle to the head great care should be taken. Hammer handles are made elliptical in cross section. The major axis of this ellipse should exactly coincide with that of the eye of the head. The reason is that the hand naturally grasps the handle so that its major axis lies in the direction of the line of motion. Hence, unless the handle is properly fitted in this particular, there will be constant danger of striking a glancing blow. The handle should also stand at right angles to a center line drawn from the ball of the pene to the face. The eye in the head is usually so set that the weight on the face side is greater than that on the pene. The effect of this is to so balance the tool that heavier and more accurate blows can be struck than if the weight were evenly balanced on each side of the eye.

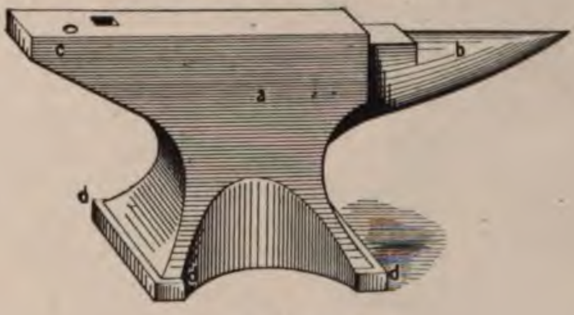


Fig. 11.

Anvils. Next to the hammer in importance is the anvil. This may be any block of metal upon which the piece to be shaped is laid. The anvil must be of such a weight that it can absorb the blows that are struck upon it without experiencing any perceptible motion in itself.

It can be shown that if a body impinges upon another of equal weight, the two will thereafter tend to move at a velocity equal to one-half of that originally possessed by the impinging body. Suppose a sledge hammer weighing fifteen pounds to be moving at the rate of 10 ft. per second. If it were to strike upon an anvil of the same weight the two (the hammer and anvil) would tend to move down at the rate of 5 ft. per second. But if, instead of this, it were to strike upon an anvil weighing 400 lbs. the tendency of the two (the hammer and anvil) would be to move on at a speed of but .36 foot = 4.3 in. per second. This velocity is easily checked and absorbed by the elasticity of the blocking on which the anvil rests.

The ordinary anvil, Fig. 11, has remained unchanged in form for many hundreds of years. As now made, the body *a* is of wrought iron to which a face of hardened steel is welded. From one end there projects the horn *b*, and the overhang of the body at the other end *c*, is called the tail. At the bottom there are four projections *d*, called the feet, which serve to increase the base upon which the anvil rests as well as to afford the means for clamping it down into position. In the tail there is a square and a circular hole. The former serves as a mortise in which cutters and similar tools may be held.

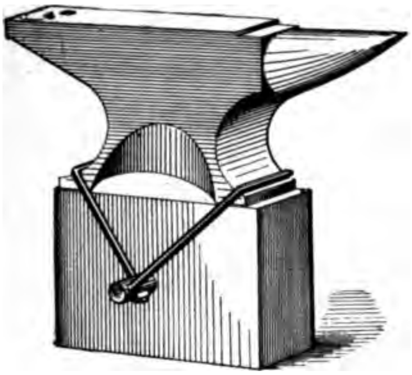


Fig. 12.

An anvil of this form serves for the execution of any work that may be desired.

Anvils are also made with a body of strong gun metal or cast iron, to which a face and horn of steel is welded.

The anvil should be placed upon the end of a heavy block of wood sunken into the ground to a depth of at least two feet, so that it may rest upon a firm but elastic foundation. As the anvil is subjected to constant vibrations, by the nature of the work, it is necessary that it should be firmly fastened to the block. In doing this avoid spiking, as the spikes will soon work loose and the block be spoiled. A very convenient and reliable method of holding the anvil is shown in Fig. 12. Here, there are two iron rods about $\frac{3}{8}$ in. in diameter passing over the feet of the anvil and running through a 1 inch round or square bar extending through the block. Nuts on these rods make it possible to draw them very tight and thus hold the anvil firmly.

Tongs. Next to the hammer and anvil in importance and usage are the tongs. They vary in size from those suitable for holding the smallest wires to those capable of handling ingots and bars of many tons in weight. The jaws are also adapted to fit over the piece to be handled and are of a great variety of shapes. As the requirements of each piece of work varies so much from that which precedes and follows it, it is customary for the blacksmith to dress his own tongs and adapt them, from time to time, to the work he has in hand. Comparatively few, therefore, of the various shapes of tongs found in shops are manufactured and for sale. A few of the general types and forms in common use are here given.

Fig. 13 represents the simplest form of tongs. These are known as flat tongs from the shape of the jaws. They are used for holding flat pieces of metal, and vary in size according to the work in hand.

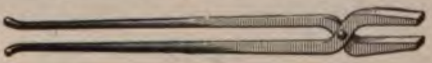


Fig. 13.

Fig. 14 shows a pair of pick-up tongs. These are used for picking up hot pieces of metal that may have fallen upon the floor. They are usually light and have long handles so that objects on the ground may be reached without stooping.

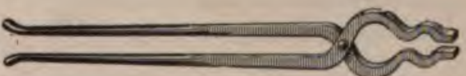


Fig. 14.

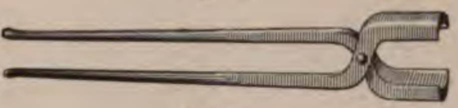


Fig. 15.

Round bit tongs are illustrated in Fig. 15. The jaws are concave and are suited for holding cylindrical objects. Tongs of this kind are frequently made of great strength and weight and are adapted to the handling of heavy shafts and axles.

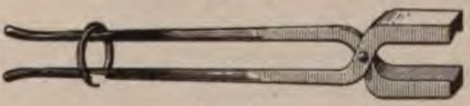


Fig. 16.

Similar tongs are used for holding square pieces. In such, the jaws have a rectangular recess as in Fig. 16, instead of a circular one. A square piece can thus be held more securely by gripping on the corners than where it is seized on the flat surface.

A common modification of these last two forms of tongs is shown in Fig. 17. These are called hollow-bit tongs. The jaws open out between the end and the pin, so that they are fitted for seizing objects that are enlarged at the extremity. It is a convenient form for handling bolts upon which the head has been upset, also similar pieces. The tongs with jaws as shown in Fig. 16 are also made in the same way.

Pincer tongs, Fig. 18, are useful for many purposes, as in holding a piece that has a rounded projection rising from the main body. A modification of this form is shown in Fig. 19.

These are the principal shapes that are to be found in all shops. As already stated, there are innumerable modifications of them. A convenient form is the box tongs, Fig. 20, where one jaw is lipped down on its edges to steady the sides of a flat piece of work. Another form is shown in Fig. 21.

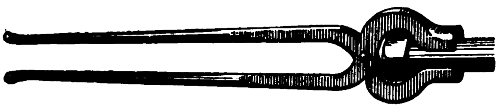


Fig. 17.

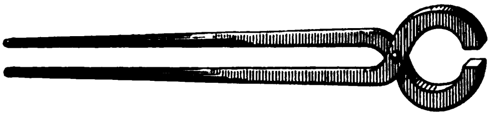


Fig. 18.

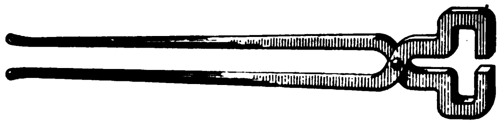


Fig. 19.

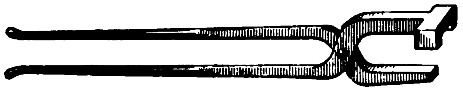


Fig. 20.

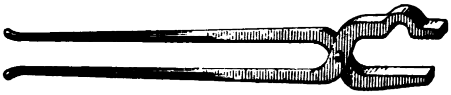


Fig. 21.

Tongs are used for holding metal that is at too high a temperature to be held in the bare hands; for placing iron in and removing it from the fire, and work of a similar character. As the hand should be free to manipulate and turn the metal, the tongs are held in position by a link driven on over the handles as shown in Fig. 16. The elasticity of the latter serves to hold the work securely.

Chisels are of two kinds, those used on hot and those intended for cold work. These differ in that the hot has a thinner and sharper blade than the cold chisel. Fig. 22 shows a hot chisel and Fig. 23 a cold chisel. Both are held on handles like a hammer head. The blacksmith holds the work in position on the anvil with his left hand, while the chisel is held at the point to be cut with the right. A helper then strikes on the head of the chisel with a sledge. The work is usually facilitated by putting an anvil cone, Fig. 24, in the square cutter hole at the tail of the anvil.

A common form of hot chisel for cutting off round bars or trimming off rough edges is shown in Fig. 25. This is known as the gouge chisel. Another, but more unusual form is the square chisel shown in Fig. 26.

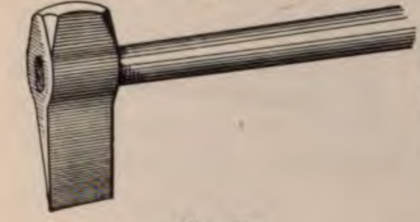


Fig. 22.

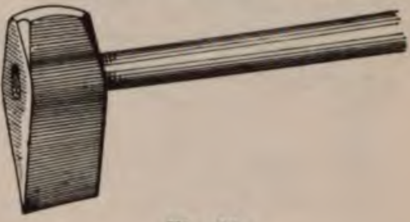


Fig. 23.

The Flatter is a tool in common use and is shown in Fig. 27. It is for smoothing off the surface of metal that is being worked and thus removes hammer marks. It is held in the same way as the chisels and is struck with a sledge by the helper. Sometimes the edges are rounded. This makes it possible to work up close to rising portions and form fillets. The flatter is also made with an offset on one side as in Fig. 28. It is then called a *foot tool.*

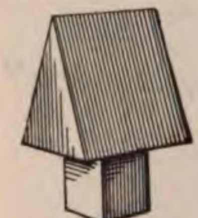


Fig. 24.

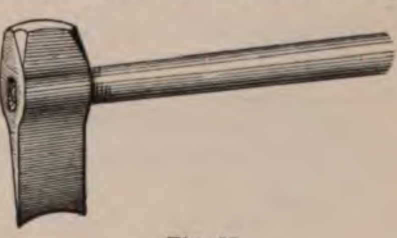


Fig. 25.

Fullers (Fig. 29), resemble the flatters in the uses to which they are put. They are also used for working into corners, Fig. 30, where it would be impossible to strike a satisfactory blow with a hammer.

The fuller shown in Fig. 29 is known as the *top-fuller.* One set in the anvil like an anvil cone (Fig. 31), is called a ***bottom-fuller.***

Punches are also made with eyes and handles like the chisels, flatters and fullers. The extremity may be square as in Fig. 32, round as in Fig. 33. of an oblong or rectangular section, according to the work at hand. The size depends upon the hole to be punched. They are invariably used for making holes through hot

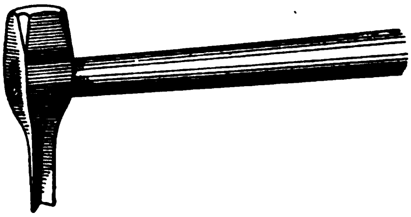


Fig. 26.

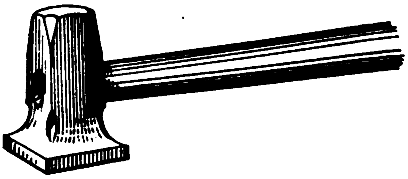


Fig. 27.

metal. The ordinary method is to punch part way through from one side; then turn the piece and drive through from the opposite direction. This avoids tearing the metal on the surface, and leaves a smooth hole at each end.

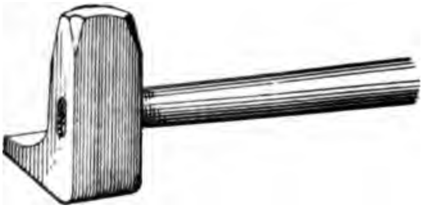


Fig. 28.

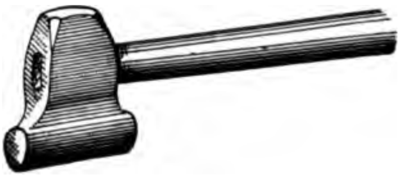


Fig. 29.

Swages are used to do work similar to that done by flatters. The difference is that they are used to form some particular shape rather than a flat surface. The most common form of swage has a concave face. It is used to smooth off a round bar. For this work a top swage (Fig. 34), which is a struck with a sledge, and a bottom swage (Fig. 35), set in the anvil are used. In connection with the use of the swage which is used for drawing metal down to a required diameter, there is another tool which is very convenient. It takes the place of both the anvil and the bottom swage and is illustrated in Fig. 36. It is usually made of cast iron of an approximately square shape, with a number of grooves of different dimensions cut on the face. These grooves are used according to the diameter and shape of the piece being worked. It is called a swage block or a sow. The grooves at B are semi-elliptical, which should also be the shape of the curve of the top swage Fig. 34. The angular grooves are right-angled and are adapted to receive different sizes of square iron. The holes through the casting are available for punching, drifting, etc.

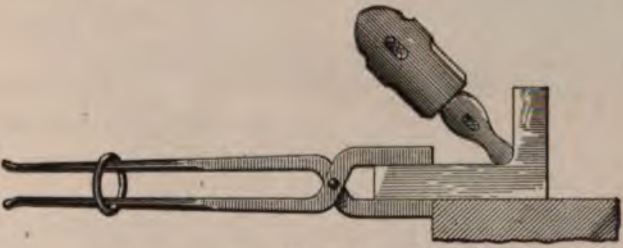


Fig. 30.

The tools here described embrace all the working tools that are to be used for general purposes. In addition to these, each blacksmith should have a set of outside calipers (Fig. 37), capable of taking in the various sizes of work that he may be called upon to make. He should also have a plain carpenter's square (Fig. 38), with the longer blade two feet in length. Where a single piece of work is to have many duplications it is well for the smith to make a pair of rigid calipers (Fig. 39), with the points ground the proper distance apart. For special work many tools may be devised; some of the more common forms of which will be described hereafter.

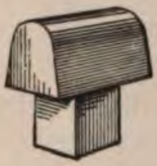


Fig. 31.

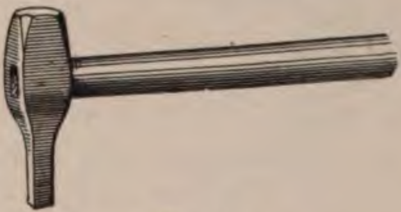


Fig. 32.

All of these tools should be kept in a tool rack standing conveniently near the anvil and forge. This rack should be so placed as not to interfere in any way with the movements of the smith or his helper. A common form of such a rack is shown in Fig. 40. It consists of a substantial table having two shelves. The upper shelf should be in the form of a tray. On each of the four sides there are racks *a a*, made of ½ inch round iron. By dropping the handles through the opening, the tools are held by the heads. In this position they are readily seen and the proper one easily selected for the work in hand. In ordinary blacksmith work the iron is heated before any work is done upon it. Exceptions are found in the case of cutting metal, and in heading down small rivets, both of which operations are frequently done cold. Of these the former is more often done. To sever a piece of cold metal nick a groove about the metal and bend to and fro. All of the bending stresses are thus concentrated at the bottom of the groove, and the metal will break almost at once. The usual method of doing this work is for the smith to hold the bar to be cut in the left hand, resting it upon the anvil at the place where it is to be severed. With his right hand he places and holds the cold chisel (Fig. 23), in position while the helper strikes it with a sledge. The bar is turned between each blow so that the chisel will travel around the bar.

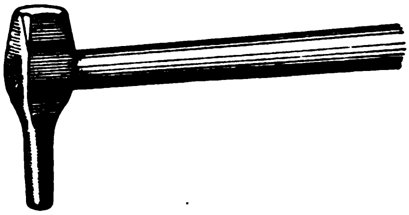


Fig. 33.

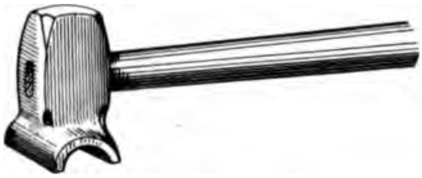


Fig. 34.

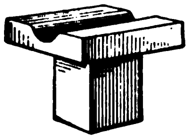


Fig. 35.

Heating Metals. Let us first consider the working of iron and steel. The temperature at which the different irons and steels may be heated without injury depends upon their quality. Ordinarily iron can be heated to a higher temperature than steel. The milder the steel, that is, the smaller the percentage of combined carbon, the higher the temperature to which it can be heated without injury. In other words, the less the variation of the steel from the condition of wrought iron the higher the temperature at which it can be worked.

Iron and steel are heated for working in order to make them more plastic and easily shaped. The higher the temperature the softer the metal becomes. As the metal is heated it rises in temperature and changes in external appearance. It is first black, then blue, then a dull red, then a bright red, (usually called a cherry red), then yellow; this yellow fades into a brilliant straw color which in turn fades into a white, at which point fusion takes place. The usual color at which wrought iron and steel are worked is that of a bright cherry red. Where a weld is to be made, however, the metal must be heated to a white heat. The higher grades of steel cannot be heated to this temperature without being ruined. By "higher grade" is meant steels with a greater percentage of combined carbon.

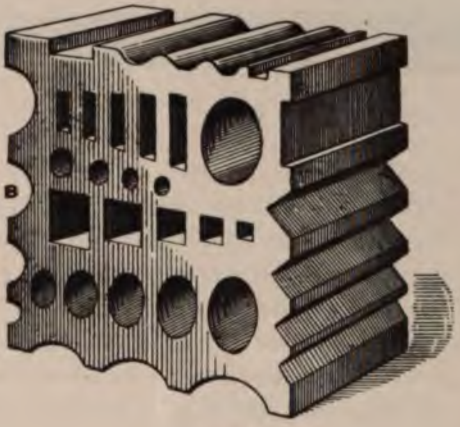


Fig. 36.

Fig. 37.

In heating metal the fire should be burned according to the work in hand. If the three bars *a*, *b* and *c* of Fig. 41 are to be heated at the unshaded sections indicated by *d*, *e* and *f* respectively, the fire must be manipulated accordingly. In the case *a* where it is to be heated but a short distance from the end, a small fire will answer. As the forge is so constructed that a fire may be burned over considerable of its area, some means must be taken to limit the fire for small work. This is usually done by saturating the coal that covers the forge beyond the limits of the desired firepot with water. This is shown to have been done in Fig. 42. The end of the bar *a* is thrust down into the fire which is confined to the pot *g* by the wet coal *h h*. The iron should be put in that portion of the fire which is the hottest. If the end of *a* in Fig. 42 were to be put down against the tuyere, the cold air issuing from the same would prevent it from becoming hot. If, on the other hand, it were laid on the top of the fire it would radiate heat so rapidly that it would not become hot. The part to be heated must, therefore, be buried in the incandescent fuel.

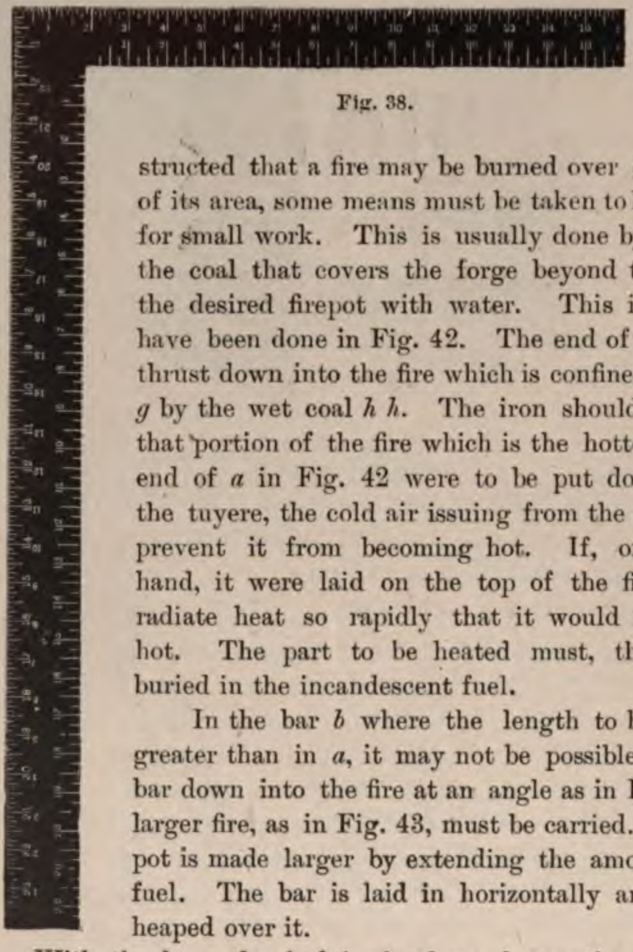


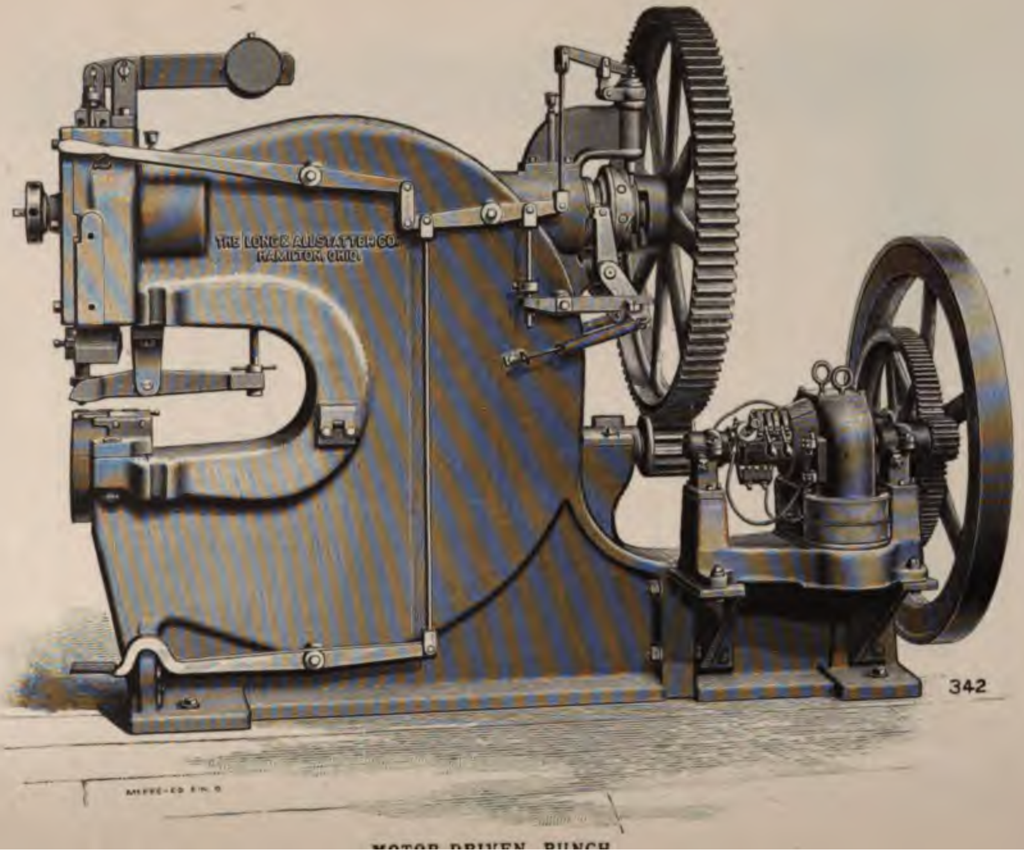
Fig. 38.

In the bar *b* where the length to be heated is greater than in *a*, it may not be possible to put the bar down into the fire at an angle as in Fig. 42. A larger fire, as in Fig. 43, must be carried. The firepot is made larger by extending the amount of dry fuel. The bar is laid in horizontally and the fuel heaped over it.

With the bar *c* the fuel is also heaped over the metal as in Fig. 44. In this case the firepot is again contracted by the use of wet coal about the edges.

These are the three typical fires. They are to be used according to the work in hand.

Wetting Coal. Combustion of coal is not greatly promoted by



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the use of water. Water is used in a forge fire to limit the size of the same. By thus limiting the size of the fire the intensity of the draft through the burning parts is increased, and with it the rapidity of combustion which is in turn followed by a higher temperature. The fuel that has been wet, cakes over and cokes from the heat. This process closes the air spaces between the pieces of coal and the draft is then forced to pass up through the burning portion.

Fig. 39.

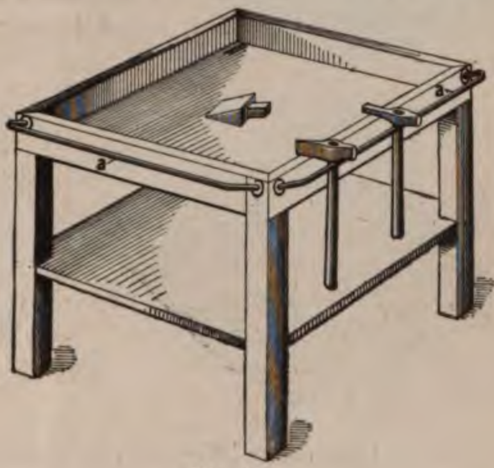


Fig. 40.

Shaping. After the metal has been heated it is shaped with the hammer. This shaping may consist of drawing, upsetting or bending. In *drawing* a bar of iron it is made longer and of a smaller diameter. *Upsetting* consists of shortening the bar with a corresponding increase of diameter. This work is usually done with a helper using a sledge hammer; the smith using a light hand hammer. They strike alternate blows. The helper must watch the point upon which the smith strikes and strike in the same place. Where two helpers are employed the smith strikes after each man. A blow on the anvil by the smith is a signal to stop striking.

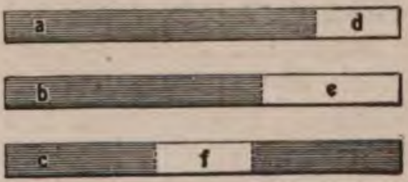


Fig. 41.

Finishing. As the hammer usually marks the metal, it is customary to leave the metal a little full and finish by the use of flatters and swages. This applies to work that has been shaped under the sledge. Light work can be dressed smoothly, and the hammer can be made to obliterate its own marks.

Wrought iron is now rolled in so great a variety of shapes that almost any desired form can be obtained direct from the mills. The more common forms are flat, round and square. These are rolled in a great range of sizes. Besides these three there are half-round, hexagonal, etc. The table on page 23 gives the corresponding weights per foot of length for flat bars.

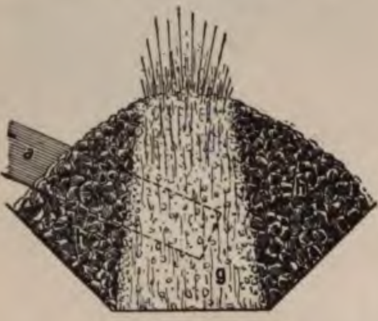


Fig. 42.

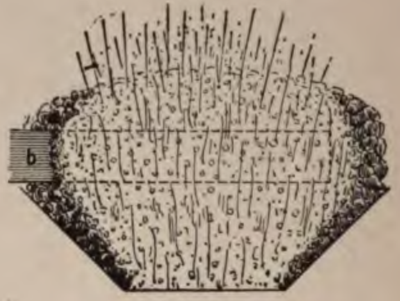


Fig. 43.

In the table on page 24 is given the weights for each foot of length of round and square bars.

When using the table on page 23 to ascertain the weight of any size of flat iron per foot of length, look in the first column at the left for the thickness. Then follow out in a horizontal line to the column giving the width. The number given will be the weight in pounds of one foot of the desired size.

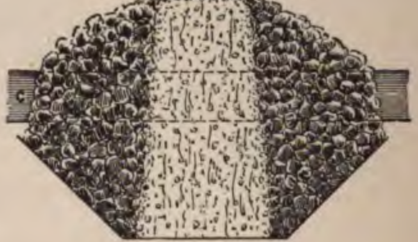


Fig. 44.

EXAMPLES FOR PRACTICE.

1. What is the weight of a bar of flat iron 1 foot long, $2\frac{1}{2}$ inches wide and $\frac{3}{4}$ inch thick? Ans. 6.25 pounds.

WEIGHT OF FLAT ROLLED IRON.

Length, 12 inches.

Thickness.	WIDTHS.																				
	½	⅝	¾	⅞	1	1⅛	1¼	1⅜	1½	1⅝	1¾	1⅞	2	2⅛	2¼	2⅜	2½	2⅝	2¾	2⅞	3
⅛	.208	.260	.313	.365	.417	.469	.521	.573	.625	.677	.729	.781	.833	.885	.938	.989	1.04	1.09	1.15	1.20	1.25
¼	.416	.521	.625	.729	.833	.938	1.04	1.15	1.25	1.35	1.46	1.56	1.67	1.77	1.88	1.98	2.08	2.18	2.29	2.39	2.50
⅜	.624	.781	.938	1.09	1.25	1.41	1.56	1.72	1.88	2.03	2.19	2.35	2.50	2.65	2.81	2.97	3.13	3.28	3.44	3.59	3.75
½	.833	1.04	1.25	1.46	1.67	1.88	2.08	2.29	2.50	2.71	2.92	3.13	3.33	3.54	3.75	3.96	4.17	4.37	4.58	4.79	5.00
⅝		1.30	1.56	1.82	2.08	2.35	2.60	2.86	3.13	3.39	3.65	3.91	4.17	4.43	4.69	4.95	5.21	5.47	5.73	5.99	6.25
¾			1.88	2.19	2.50	2.81	3.13	3.44	3.75	4.06	4.38	4.69	5.00	5.31	5.63	5.94	6.25	6.56	6.88	7.19	7.50
⅞				2.55	2.92	3.28	3.65	4.01	4.38	4.74	5.10	5.46	5.83	6.19	6.57	6.92	7.29	7.65	8.02	8.38	8.75
1					3.33	3.75	4.17	4.58	5.00	5.42	5.83	6.25	6.67	7.08	7.50	7.91	8.33	8.75	9.17	9.58	10.00
1⅛						4.22	4.69	5.15	5.63	6.09	6.56	7.03	7.50	7.97	8.44	8.90	9.38	9.84	10.31	10.78	11.25
1¼							5.21	5.73	6.25	6.77	7.29	7.81	8.33	8.85	9.38	9.89	10.42	10.94	11.46	11.98	12.50
1⅜								6.30	6.88	7.45	8.02	8.59	9.17	9.74	10.32	10.88	11.46	12.03	12.60	13.17	13.75
1½									7.50	8.12	8.75	9.37	10.00	10.62	11.25	11.87	12.50	13.12	13.75	14.37	15.00
1⅝										8.80	9.45	10.14	10.83	11.51	12.19	12.86	13.54	14.22	14.90	15.57	16.25
1¾											10.21	10.94	11.67	12.40	13.13	13.85	14.58	15.31	16.04	16.77	17.50
1⅞												11.72	12.50	13.28	14.06	14.84	15.63	16.41	17.19	17.97	18.75
2													13.33	14.16	15.00	15.83	16.67	17.50	18.33	19.16	20.00
2⅛														15.05	15.94	16.81	17.71	18.59	19.48	20.36	21.25
2¼															16.88	17.80	18.75	19.69	20.63	21.56	22.50
2⅜																18.80	19.79	20.78	21.78	22.76	23.75
2½																	20.83	21.87	22.93	23.96	25.00
2⅝																		22.97	24.07	25.16	26.25
2¾																			25.21	26.35	27.50
2⅞																				27.55	28.75
3																					30.00

2. What is the weight of a bar of flat iron 4 feet 6 inches long, 2 inches wide and 1 inch thick? Ans. 30 pounds.

3. What is the weight of a bar of flat iron ½ inch thick, 3 inches wide and 14 feet long. Ans. 70 pounds.

The weight of any piece of wrought iron can be calculated in the same way as directed for cast iron in "Foundry Work," page 32, except that the constant coefficient used is .2777 instead of .2607. The rule thus becomes,

Multiply the volume of the piece of iron in cubic inches by .2777 or in the case of mild steel *multiply by .2833.*

EXAMPLES FOR PRACTICE.

1. What is the weight of a piece of wrought iron containing 1,824 cubic inches? Ans. 367.67 pounds.

2. What is the weight of a wrought iron plate ¾ inch thick and 2 feet square? Ans. 120 pounds (nearly).

3. What is the weight of a plate of wrought iron ½ inch thick, and in the shape of an equilateral triangle whose sides have a length of 24 inches? Ans. 34.64 pounds.

WEIGHTS OF ROUND AND SQUARE ROLLED IRON.

Length, 12 inches.

Thickness or Diameter in Inches.	Weight of Square Bar One-Foot Long.	Weight of Round Bar One Foot Long.	Thickness or Diameter in Inches.	Weight of Square Bar One Foot Long.	Weight of Round Bar One Foot Long.	Thickness or Diameter in Inches.	Weight of Square Bar One Foot Long.	Weight of Round Bar One Foot Long
0			11/16	24.08	18.91	⅜	96.30	75.64
1/16	.013	.010	¾	25.21	19.80	7/16	98.55	77.40
⅛	.052	.041	13/16	26.37	20.71	½	100.8	79.19
3/16	.117	.092	⅞	27.55	21.64	9/16	103.1	81.00
¼	.208	.164	15/16	28.76	22.59	⅝	105.5	82.83
5/16	.326	.256	3	30.00	23.56	11/16	107.8	84.69
⅜	.469	.368	1/16	31.26	24.55	¾	110.2	86.56
7/16	.638	.501	⅛	32.55	25.57	13/16	112.6	88.45
½	.833	.654	3/16	33.87	26.60	⅞	115.1	90.36
9/16	1.055	.828	¼	35.21	27.65	15/16	117.5	92.29
⅝	1.302	1.023	5/16	36.58	28.73	6	120.0	94.25
11/16	1.576	1.237	⅜	37.97	29.82	⅛	125.1	98.22
¾	1.875	1.473	7/16	39.39	30.94	¼	130.2	102.3
13/16	2.201	1.728	½	40.83	32.07	⅜	135.5	106.4
⅞	2.552	2.004	9/16	42.30	33.23	½	140.8	110.6
15/16	2.930	2.301	⅝	43.80	34.40	⅝	146.3	114.9
1	3.333	2.618	11/16	45.33	35.60	¾	151.9	119.3
1/16	3.763	2.955	¾	46.88	36.82	⅞	157.6	123.7
⅛	4.219	3.313	13/16	48.45	38.05	7	163.3	128.3
3/16	4.701	3.692	⅞	50.05	39.31	⅛	169.2	132.9
¼	5.208	4.091	15/16	51.68	40.59	¼	175.2	137.6
5/16	5.742	4.510	4	53.33	41.89	⅜	181.3	142.4
⅜	6.302	4.950	1/16	55.01	43.21	½	187.5	147.3
7/16	6.888	5.410	⅛	56.72	44.55	⅝	193.8	152.2
½	7.500	5.890	3/16	58.45	45.91	¾	200.2	157.2
9/16	8.138	6.392	¼	60.21	47.29	⅞	206.7	162.4
⅝	8.802	6.913	5/16	61.99	48.69	8	213.3	167.6
11/16	9.492	7.455	⅜	63.80	50.11	¼	226.9	178.2
¾	10.21	8.018	7/16	65.64	51.55	½	240.8	189.2
13/16	10.95	8.601	½	67.50	53.01	¾	255.2	200.4
⅞	11.72	9.204	9/16	69.39	54.50	9	270.0	212.1
15/16	12.51	9.828	⅝	71.30	56.00	¼	285.2	224.0
2	13.33	10.47	11/16	73.24	57.52	½	300.8	236.3
1/16	14.18	11.14	¾	75.21	59.07	¾	316.9	248.9
⅛	15.05	11.82	13/16	77.20	60.63	10	333.3	261.8
3/16	15.95	12.53	⅞	79.22	62.22	¼	350.2	275.1
¼	16.88	13.25	15/16	81.26	63.82	½	367.5	288.6
5/16	17.83	14.00	5	83.33	65.45	¾	385.2	302.5
⅜	18.80	14.77	1/16	85.43	67.10	11	403.3	316.8
7/16	19.80	15.55	⅛	87.55	68.76	¼	421.9	331.3
½	20.83	16.36	3/16	89.70	70.45	½	440.8	346.2
9/16	21.89	17.19	¼	91.88	72.16	¾	460.2	361.4
⅝	22.97	18.04	5/16	94.08	73.89	12	480.	377.

In the actual work of the blacksmith shop one of the simplest jobs is the making of an ordinary staple, Fig. 45. The first stages of this are shown at *a* and *b* of Fig. 46. The iron is first cut to a suitable length *a*. It is then heated first at one end then at the other and pointed as at *b*. This pointing is done on the flat face of the anvil while the metal is hot. It should be noted that the pointing draws the metal out somewhat. Hence the piece is longer in the condition *b* than it was in the condition *a*. Allowance for this must be made in cutting off the metal. After pointing, the iron is bent to its final shape over the horn of the anvil. One end is held between the jaws of a pair of flat tongs as in Fig. 47, while the other end is struck by a hammer as shown. If the iron is $\frac{3}{8}$ inch in diameter or less it may be bent cold. If more than $\frac{3}{8}$ inch in diameter it is well to heat it for more than half its length and bend while still hot after pointing. When needed in large quantities staples of this kind are made complete by machinery. U bolts, Fig. 48, are made in the same way. The threads are cut while the iron is still straight.

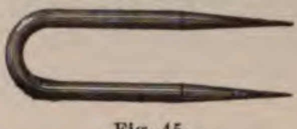


Fig. 45.

In drawing iron there is always a little waste due to the formation of scale and the action of the fuel. This is usually so small in amount that it can be neglected. Where it is possible to trim the finished forging, the amount of metal originally cut off is more than sufficient to allow for the drawing or upsetting. In the case of the staple, Fig. 45, the exact allowance should be made. If it is not so made, the smith can vary the sharpness of the pointing. The more gradual the taper the longer the staple. As there is no appreciable loss of metal the weight and therefore, the bulk of the material may be considered to be the same before and after drawing or upsetting.

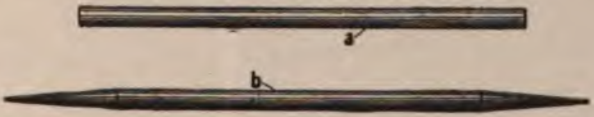


Fig. 46.

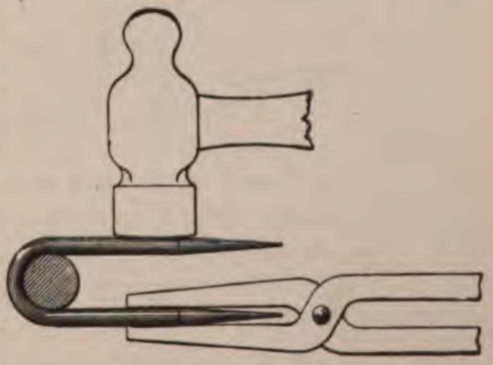


Fig. 47.

EXAMPLES FOR PRACTICE.

1. What will be the final length of a bar of round iron $1\frac{1}{2}$

inch in diameter and 6 feet long, 18 inches of which is to be drawn down to a diameter of ¾ inch.

Ans. 10 feet 6 inches.

2. A staple is to be made of ⅜ inch round iron; it is to be 13 inches long over all and the taper is to extend back for 2½ inches from the ends. What length of metal must be cut from the bar in order to make it? Ans. 9⅔ inches.

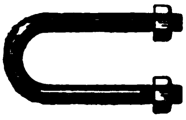


Fig. 48.

3. It is desired to have a square shank having a side of 1 inch and a length of 6 inches on the end of a rod 1¼ inches in diameter. What length of the round metal will be required for the square shank?

Ans. 4.89 inches.

4. A head is to be upset on the end of a rod 1 inch in diameter. This head is to be cylindrical, ¾ inch long and 1¾ inches in diameter. What length of 1 inch rod must be allowed to make the head? Ans. 2.3 inches.

Bolts. In direct distinction from the *drawing out* of the point of the staple just described is the *upsetting* of the head of a bolt. *Drawing out* or *drawing down* may be defined as the reducing of a bar of metal to a smaller diameter or smaller cross-sectional area. *Upsetting* is the reverse of drawing out and "consists of making a thin bar of iron into a thick one," either for a whole or a portion of its length. To form the head of an ordinary bolt make the width between the parallel sides equal to 1½ times the diameter of the bolt, plus ⅛ inch. The depth of the head is equal to one-half of the width of the head. Thus, the dimensions of the head of a ¾ inch bolt are $.75 \times 1.5 + .125 = 1.25 = 1\frac{1}{4}$ inches for the length of the side and $1\frac{1}{4} \div 2 = \frac{5}{8}$ inch for the depth of the head. The cubic contents of such a head is therefore, $.625 \times 1.25 \times 1.25 = .9766$ cubic inches. As the area of a ¾ inch bar is about .44 square inch it follows that the length to be allowed for upsetting the head is,

$$\frac{.9766}{.44} = 2.22 - \text{ or about } 2\frac{1}{4} \text{ inches.}$$

Where large quantities of bolts are to be made the bars are heated in a furnace and headed by special machinery. Where the work is done by hand the tools are of the simplest character.

The header consists of a disc in which a hole has been drilled to correspond to the diameter of the bolt. A handle 12 or 15 inches in length is welded to the disc. Such a tool is shown in Fig. 49. The hole should be about $\frac{1}{32}$ inch larger than the nominal size of iron. To make a bolt with this tool: First cut off the iron to the required length; then heat the end to be headed, to a dull straw color; strike the end with a hammer or against the anvil and upset it so that the portion intended for the formation of the head will not pass through the header. Then place the hole of the header over the square hole in the tail of the anvil and drop the cold end of the bolt through it. Strike the projecting portion of the bar and upset it until the requisite thickness of head is obtained. This will probably leave a head of curved but irregular outline. Remove from the header and square the head thus upset on the face of the anvil. This will probably thicken the head. Again drop the cold end through the header and strike the head until it is reduced to the proper thickness. After which, again square the edges on the face of the anvil. In doing this work, the smith will hold the header in his left hand. The work will be facilitated if a helper assists with a sledge hammer.

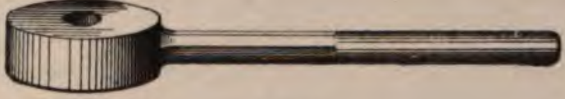


Fig. 49.

There are a number of simple tools in use for clamping the bar while it is being headed so as to avoid the preliminary upsetting.

We have now studied the methods to be followed in the execution of two simple jobs. One involved drawing out and the other upsetting. Sometimes both processes must be followed in one job. Where there is a choice between the two the smith should take the one involving the least amount of work.

Welding. The process of welding consists of heating the faces of the two pieces to be joined until they are at the point of fusion (called the welding heat), then uniting them by blows or pressure. The temperature of iron when at a welding heat is

1900° Fahrenheit. The appearance of the metal is nearly white and when exposed to the air it will emit bright sparks. It will also give forth a slight noise similar to that produced by the escape of a small jet of steam. The theory of welding is that the semi-liquid particles of the metal are pressed into the same condition of close contact that they have in other parts of the bar. Interposition of foreign matter between the two pieces to be joined will prevent welding. The three things that most commonly intervene to prevent welding are air, scale and dirt. Air intervenes when the two surfaces to be welded form a pocket upon being brought together. This occurs when they touch only at the edges and one or both of the surfaces are concave.

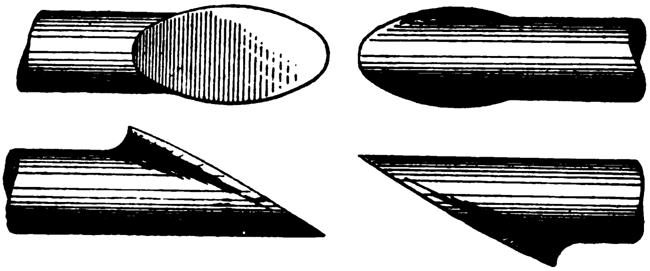


Fig. 50.

If iron is heated to any temperature above a cherry red its affinity for oxygen increases. When at a straw color or hotter the affinity is very great. This affinity results in the production of an oxide of iron known as *scale*. If scale forms on the surface of the metal between the time that it is drawn out of the fire and the weld made, it will prevent the union over such area as it covers. The welding of all metals is not done at the same temperature. Welding demands a certain condition of plasticity of surface. If this condition is not reached welding fails for want of contact due to excessive oxidation. The temperature of this certain condition of plasticity varies with the composition of the iron. For this reason irons having different welding points cannot be soundly welded to each other in an oxidizing flame.

In order to prevent the formation of scale and to permit the welding of irons of different compositions, a flux is used. As defined in "Foundry Work," page 10, a flux is, "a substance that promotes the fusing of metals."

For welding iron, clean river sand or powdered sandstone makes a good flux. It is useless, however, for welding steel or steel and iron. For this purpose borax is generally used. The flux is applied shortly before the metal reaches the welding heat, no matter what the temperature of that heat may be. It melts on the surface of the metal, forming a slag, which covers the surface to be welded and prevents oxidation. When the two surfaces are brought together and subjected to a pressure or blows, the slag flows or is pressed out from between those surfaces and actual contact is secured.

Surfaces to be welded are first shaped suitably for the purpose. Ordinarily when two bars are to be welded each is beveled as shown for round bars in Fig. 50. This beveling is called *scarfing*, and should be so done, that when the weld is complete there is but a slight enlargement of the newly formed bar at that point. For heavy work where the metal must remain in the fire for a long time in order to reach the welding heat, there is a different method of scarfing. This is shown in Fig. 51. One piece is opened in the form of a jaw, the other is wedge-shaped and fits the former. Where the weld is to be made between heavy pieces, the surfaces should be left convex as at A A in Fig. 51. This facilitates the outflow of the slag and the escape of all other impurities.

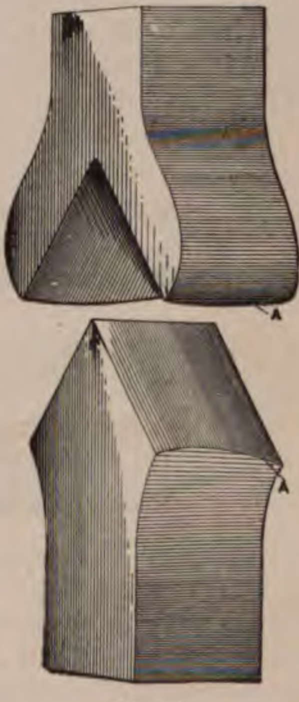


Fig. 51.

Sometimes a weld is made without scarfing; such is called a *butt* weld. This is best done by slightly rounding the ends that are to be joined, as shown in Fig. 52. As the ends are forced together the metal flows outward forming a ring as in Fig. 53. This is then hammered down to the diameter of the bar by the use of the top and bottom swages, Figs. 34 and 35.

When a small bar is to be welded to a heavier piece of metal and a butt weld is used, it is said to be *jumped* on. Such a weld is shown at A of Fig. 54. In preparing the parts for this weld the bar should be rounded at the end as shown in Fig. 52, and the heavy piece left flat or slightly cupped. When the weld is being made the metal will flow out about the point of union. This metal should afterwards be fullered down to form a fillet as shown in Fig. 30.

The edges of the scarf will burn away to a certain extent in heating. The scarf should therefore be made enough larger that the weld may be of full size after completion. All scarfs should be slightly rounding, in order to permit the escape of air and slag. The heating can best be done in a clear fire of coal containing little gas. In making heavy welds, heat slowly. If an attempt is made to heat large pieces too rapidly, the interior will not be heated sufficiently. Turn the metal in the fire frequently in order to heat evenly and avoid burning. Withdraw occasionally from the fire and sprinkle with flux. When welding strike light blows at first and heavy ones thereafter. As soon as the pieces are joined, strike so that the edges of the scarf will be closed. This will prevent the joint of the weld from showing when the work is completed.

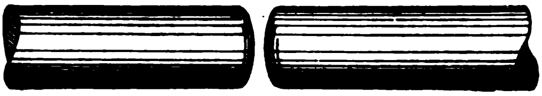


Fig. 52.

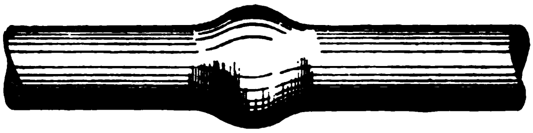


Fig. 53.

Sand can be used as a flux for welding iron. For welding steel, borax should be used. To weld steel successfully the following precautions should be observed. Clean the fire of all cinders and ashes. Put sufficient coal upon the fire so that it will be unnecessary to add more coal while taking the welding heat: Upset both pieces near the end and scarf carefully: When possible, punch a hole and rivet the two pieces together: Heat the steel to a low cherry heat and sprinkle with borax: Replace in the fire and raise to the welding heat: Clean the scarfed surfaces and strike lightly at first, followed by heavier blows. The appearance of steel when at a welding heat is a pale straw color. German steel can be heated to about the same temperature as iron.

Steel may also be welded to wrought iron. This is done in the manufacturing of edged tools. The body of the tool is of iron, to which a piece of steel is welded and forms the cutting edge. This class of work is best done with a fire of anthracite coal, though coke or charcoal may be used. The fire should be burning brightly when the heating is done. Lay the iron and steel on the coal until they are red hot. Then sprinkle the surfaces of both with the flux and let it vitrify. A convenient method of doing this is to have the powdered flux (borax preferred) in a pepper-pot. As soon as the heat has changed the metals to a straw color lay them together and strike. A single blow of a drop hammer, or four or five with a light sledge will do the work. Be sure that these pieces are well covered with a flux before attempting to weld.

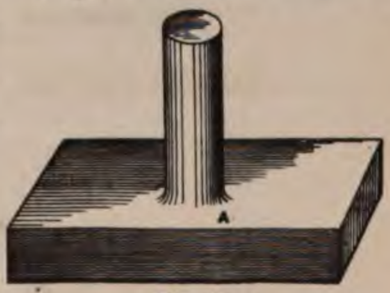


Fig. 54.

Two pieces of high grade steel can also be welded in the same manner.

No attempt should be made to do this class of work in an ordinary forge like that illustrated in Figs. 4 or 5. The forge or furnace should be especially built for burning anthracite coal. Such a furnace is shown in Fig. 55. This furnace is suited for hard coal or coke. It is fed from the hoppers shown at each end, and can be cleaned through the pan at the bottom. The metal to be heated is laid on top of the coals beneath the brick roof.

When burning anthracite coal, the top of the bed of fuel should not be disturbed. The poker should only be used beneath. Soft or bituminous coal fires can be raked over on the top. An anthracite fire can only be retained by banking and admitting enough draft beneath the fuel to keep it ignited. The simplest method of retaining a bituminous coal fire, when not in use, is to thrust a piece of hard wood down into the bed of coals and cover with a thin layer of ashes. To start the fire again, rake off the ashes, and put on the blast. The wood will quickly ignite and set fire to the coal.

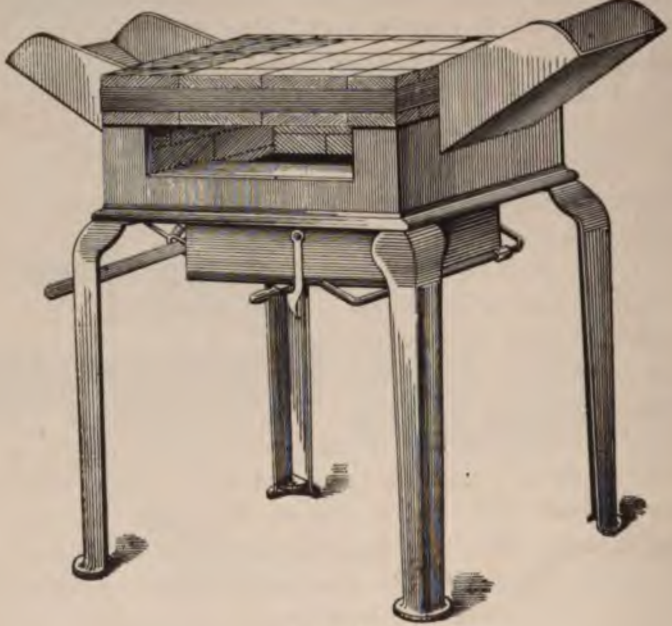


Fig. 55.

Eye Bolt. The making of an eye bolt is a common piece of work. It may be made in either one of two ways. The easier method produces an eye shaped as in Fig. 56. To make such a bolt, first scarf the end so that it will fit over the bend of the rod along the dotted line *a b*. Bend the eye over the horn of the anvil. Finally bring to a welding heat and weld in accordance with instructions already given.

An eye of better appearance as shown in Fig. 57 is made as follows: Upset the body of the metal as a seat for the scarf at the end, shown at *a* Fig. 58. Scarf the end of the bar and bend over the horn of the anvil into a true circle to fit the seat at *a*, and then weld as before.

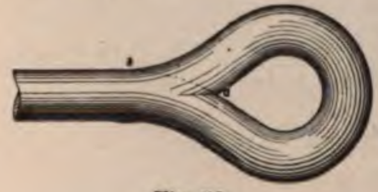


Fig. 56.

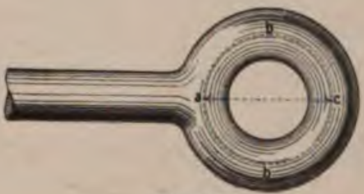


Fig. 57.

The length of metal required for an eye or ring is nearly equal to the length of the circumference of a circle whose diameter is equal to the mean diameter of the ring. Thus in Fig. 57 the length required for the eye will be approximately the length of the circle *a b c b* whose diameter is *a c*.

Hooks. The making of hooks to be used for hoisting and other purposes is important. Such a hook is shown in Fig. 59. It is made with an eye for the reception of a chain and varies in size between that eye and the point. This variation is for the purpose of so distributing the metal that the hook will be the strongest at those points where it is subjected to the greatest stress. If we consider the depth of the metal to be $2\frac{3}{4}$ inches with a width of $1\frac{7}{8}$ inches at the point of largest section, the hook shown can well be made of iron $2\frac{1}{4}$ inches in diameter.

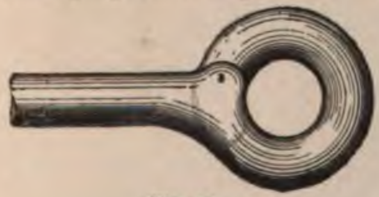


Fig. 58.

In choosing the metal to be used for a hook, select a bar having about the same sectional area as the largest section of the hook. This will require the least amount of drawing out. For the hook shown in Fig. 59, a length of about $10\frac{1}{2}$ inches will suffice. It will be better, however, to cut off at least 12 inches for the first one. If a number are to be made, subsequent hooks may be forged without waste. For the first it is better to use ample stock so that the work may not be spoiled. The bar should first be drawn out to the shape of the hook as in Fig. 60. As thus drawn, it will be a little longer than the inside of the hook. After drawing, weld in the eye as already directed for eyes. Then bend the hook into shape over the horn of the anvil. This bending will shorten the metal on the inner curve of the hook a very little, and lengthen it on the outer. The amount of the change in dimensions will depend upon the temperature at which the work is done. After completion the work should be carefully finished under the swage.

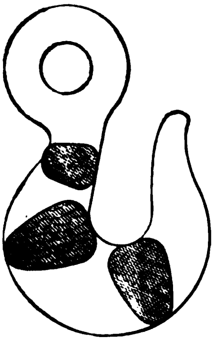


Fig. 59.

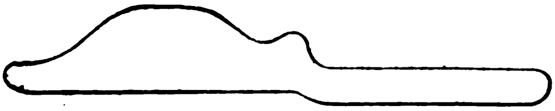


Fig. 60.

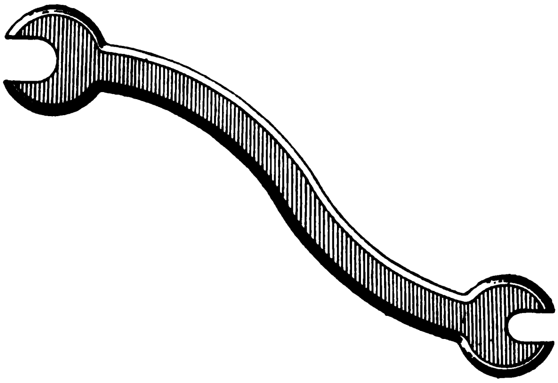


Fig. 61.

Where large numbers of such hooks are to be duplicated they are stamped out under a steam hammer or a drop.

Wrenches. A simple tool that is frequently called for is the S wrench. This wrench is usually made with a gap at each end, suited for nuts of different sizes. It is shown complete in Fig. 61.

The jaws at the end should be parallel with each other. A line drawn from one jaw to the other should make an angle of 30 degrees with the center line of each jaw. There are two ways in which such a wrench can be forged. One is to forge the jaws separately and then weld to the handle. In the other the jaws are cut from a solid piece of metal and the iron between is then drawn down to the proper size for the handle. The latter is preferable, since it avoids all welds. To make the wrench by the second process, select a piece of steel large enough to form the head. Fuller it down back of the head as shown in A Fig. 62, at *a a*. Round the end and punch the hole *b*. Next treat the other end in the same way and draw out the intermediate metal giving the form shown at B. Now cut out the holes *b b* securing the form shown at C. It now remains to bend the heads to the proper angle and give the desired curve to the shank. In forging such a wrench the outer edges should be slightly rounded so that they will not cut the hand. The inside of the jaws should be perfectly square with sharp edges. This finish can be best obtained by filing.

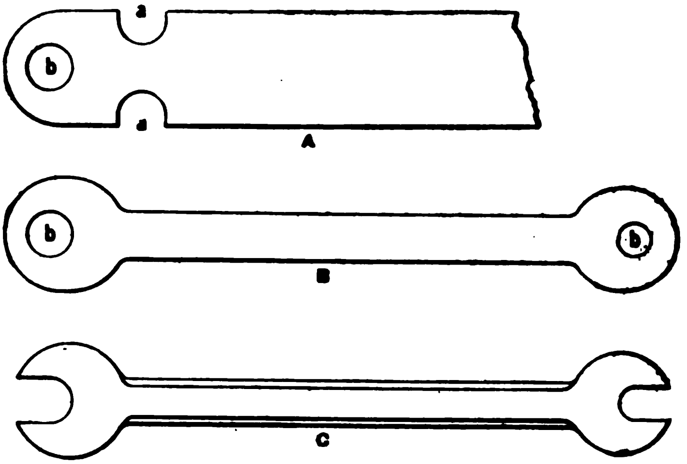


Fig. 62.

Hammer Heads are usually made in dies and by power. The various forms through which the metal passes in die forging will serve as a guide for making a hammer head by hand. If a ball pene hammer like that shown in Fig. 7 is to be made, the work can best be done from a flat bar. Take a flat bar of suitable size for the hammer. This size is one that has about the same depth as the eye and a thickness equal to the body at that point, or enough more, so that the sectional area of the untouched bar shall be a little more than the area of the hammer's face. The heating can be done either in a soft coal fire or an anthracite furnace, as shown in Fig. 55. The latter is preferable. Heat the end of the bar only. Do not raise the temperature above a cherry red. After the first heating hammer out the peen so that the end of the bar has the shape shown in Fig. 63. This work can be done with the fuller, Fig. 29, and the cupping tool, Fig. 64. After drawing down the end of the rod with the flatter (Fig. 27), the fuller is used to work out the groove *a*. The cupping tool, whose face is that of a hollow sphere, assists in rounding the face of the pene. The pene should first however be given a rough spherical outline with the hammer alone. If the bar is of the exact size of the body no work need be done here. If not, then forge down to approximately the proper size. Next forge the body of the hammer and cut down in front of the face, still leaving it attached to the bar as shown in Fig. 65. The grooves at *a* and *b* can be worked out with the fuller.

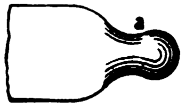


Fig. 63.

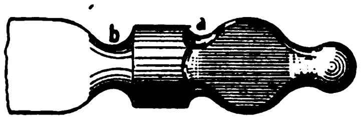


Fig. 65.

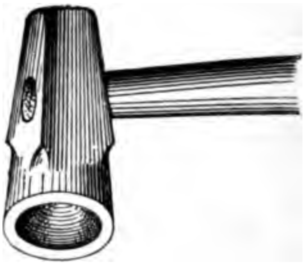


Fig. 64.

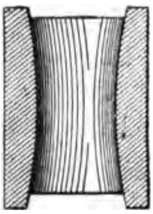


Fig. 66.

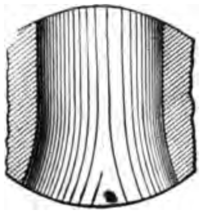
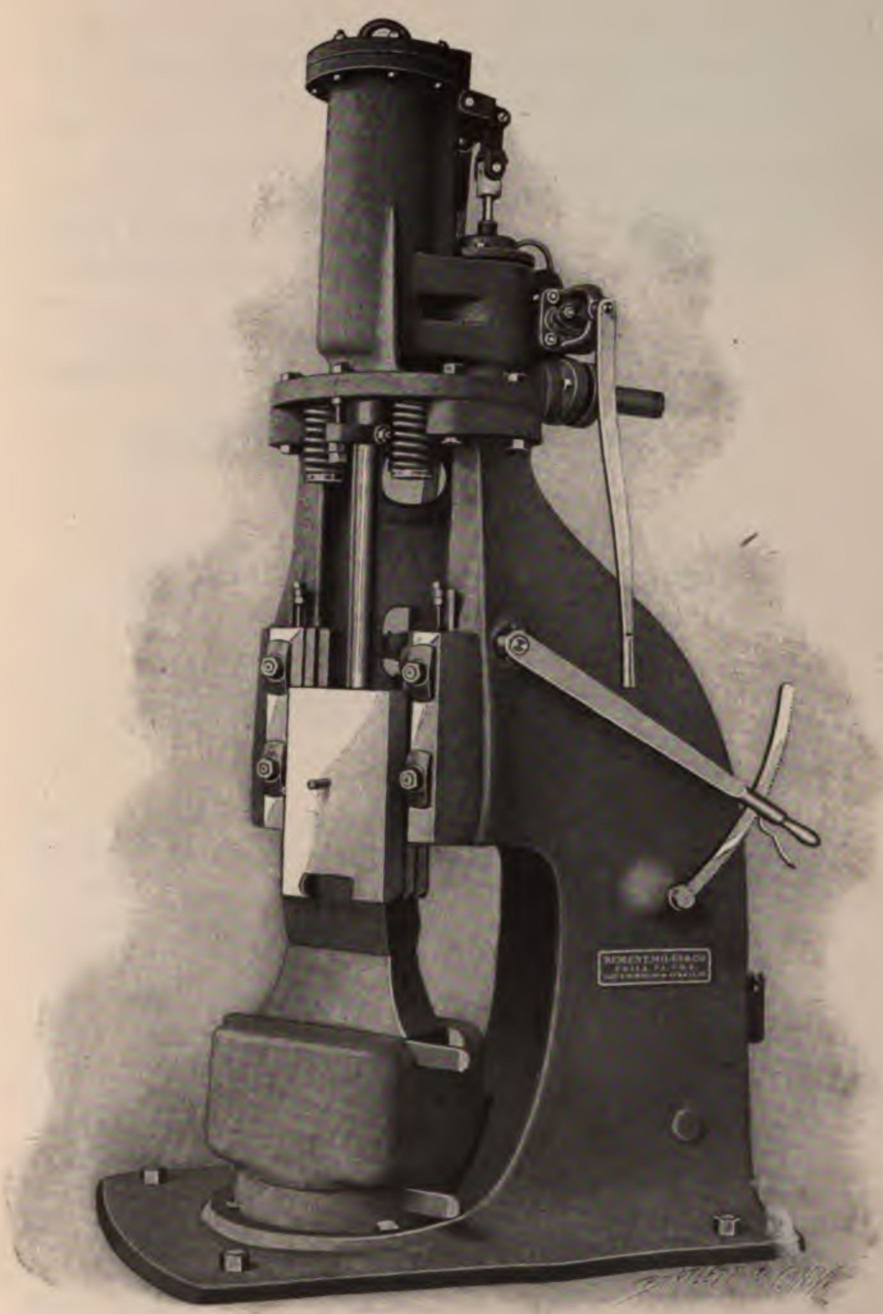


Fig. 67.

The next step is to punch the eye. This eye should not be straight. It must be tapered out each way from the center, where the eye is to be of the smallest section. The taper must run both lengthwise and across the hole as shown in Figs. 66 and 67.



800-POUND BEMENT SINGLE-FRAME STEAM HAMMER.

Niles-Bement-Pond Company.

To form this, the taper punch must be driven in at the two sides of the head alternately until the eye has been enlarged to the proper size.

After the completion of this work the head may be cut free from the bar. It should then be ground. If a very good job is wanted, the head should be sent to the machine shop and turned. When this has been done it should be tempered, as will be directed later.

Tongs. Every blacksmith is constantly being called upon to make his own tongs. As already stated, these tools must be of a great variety of shapes in order to meet the demands of the shop. The different styles required are not upon the market. There are two methods of forging tongs. One is to make the jaw and handle of a single piece without a weld; the other is to forge the jaw and weld on the handle.

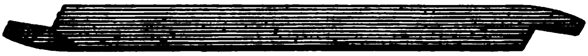


Fig. 68.

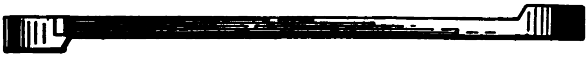


Fig. 69.

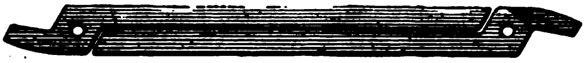


Fig. 70.

For light tongs the first method is preferable ; for heavy, the second.

To make a pair of light tongs of the shape shown in Fig. 13, take a piece of iron $\frac{1}{2}$ inch × $1\frac{1}{4}$ inches. Forge down the ends until the bar is in the form shown by Figs. 68 and 69. Punch the eyes and split the bar into two pieces as shown in Fig. 70. Hammer the handle into a round section and rivet the two parts together.

For heavy tongs a piece of flat iron of suitable size should be forged into the jaw, after which the handles are welded. The method of doing the work in the two cases is the same, except that the forging is heavier and two welds are required.

Rings and Chains. Rings and chains are made in a manner similar to that used for eyebolts. The metal is cut off to the proper length and the ends are scarfed as shown in Fig. 50. It is then bent to the desired form of link or ring and the scarfed surfaces brought together. After reheating to the proper temperature, the weld is made. In making chains, the links are successively bent through the one preceding and then welded in position.

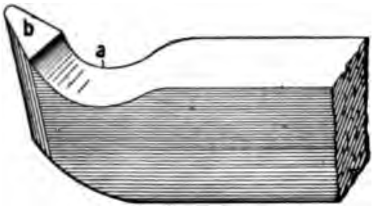


Fig. 71.

Tool Dressing is usually considered one of the most particular jobs in a shop. The work is light and a helper is always used for the striking. The material used is known as *tool steel.* It is a high grade of metal and contains a large amount of combined carbon. The details of this steel are given in "Metallurgy." Tools are of many shapes. Nearly all those used in a machine shop can be made with a fuller and flatter. The shank of the tool is usually left the full size of the untouched bar. This statement applies to the lathe and planer tools and cold chisels. The machine tools are made of steel having a rectangular section. Cold chisels and punches are commonly made of octagonal steel.

As an example of a tool to be forged take what is known as a "front tool." This tool is shown in Fig. 71. The metal used is of a size suited to enter the tool post of the lathe for which it is intended. The metal is drawn out and the hollow *a* made with the fuller. The point *b* is shaped by the hammer and cut to an approximate shape with a hot chisel. It is well to grind the tool into a working shape before tempering. It should not, however, be sharpened.

Cold chisels are made by simply flattening one end of a bar of (preferably hexagonal) steel and grinding to a suitable edge.

Double ended or sizing cutters are usually made in the machine shop and sent to the blacksmith shop for hardening. The steel of which such tools are made is first cut off and annealed in the blacksmith shop.

Tools for woodworking machinery are first cut from the bar and annealed. They are then shaped and afterwards hardened.

Tempering. The general process of tempering is described in "Metallurgy." Steel is hardened by cooling suddenly and softened by cooling slowly from a red heat. In hardening, care should be taken to plunge the tool into the water or oil vertically, so that there may be no uneven cooling of the sides. For iron working tools, plunge into the water only that portion of the tool that is to be tempered. This avoids brittleness in the supporting portions. It also enables enough heat to be stored in the metal to supply that needed for tempering.

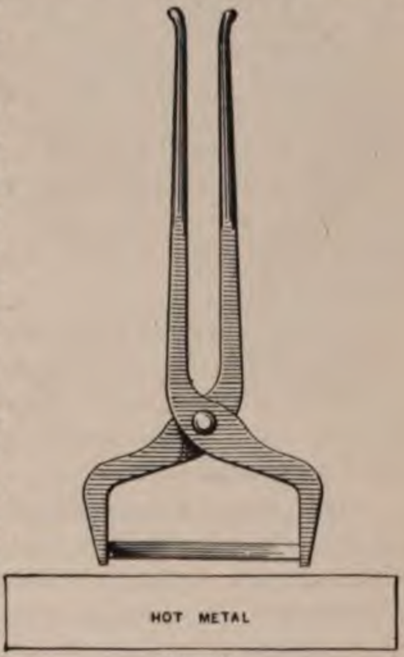


Fig. 72.

As wood working tools are lighter, and as a partial cooling would be apt to cause warping or even cracking of the metal,it is customary to plunge them into the bath. The result is that they are cooled and hardened throughout. The reheating of these tools is done by means of an outside source, which must be capable of imparting a uniform temperature to all parts of the tool. If the heat so imparted is not uniform the tool will be warped. Where a large number of tools are to be tempered an anthracite coal fire is used. For this purpose a furnace similar to that illustrated in Fig. 55 is used. Where an anthracite fire is not available a hot iron can be advantageously employed. Take a piece of flat iron an inch or more in thickness and having a larger surface than that of the tool to be tempered. Heat it to a bright cherry red and laying it on the anvil, hold the tool about half an inch above it. Hold by the edges as shown in Fig. 72, if possible. When the heat from the metal has raised the tool to the desired temperature as indicated by the color, plunge it into the bath of water or oil. Do not plunge it in flatwise as held in Fig. 72. The cooling of the under side of the tool before the upper will cause warping. Put the tool into the bath edgewise.

Another method of heating large wood working tools, such as saw plates and the like, is to submerge them in a bath of molten lead. This communicates an absolutely even temperature to the plate. It also has the advantage that no overheating can occur. The color at which the desired temperature is attained for various classes of tools is given in "Metallurgy."

Annealing is a process of softening steel. It is done so that it may be easily worked with hand or machine tools. It is accomplished by slowly cooling from a red heat. The usual method is to heat the piece red hot and then bury in lime or ashes. It is allowed to remain there until it is thoroughly cold. Twelve hours should be allowed for this work. For this purpose lime is better than ashes, as it is a poorer conductor of heat; hence the piece cools more slowly.

Another and quicker way of annealing is by the water method. The steel is heated to a cherry red and allowed to cool in a dark place until the red just disappears. It is then quickly plunged into cold water. This method should never be used when there is time to wait for the other.

Hardening and Annealing Brass. The process of hardening and annealing brass is exactly the reverse of that used with steel. Brass is hardened when it is heated and allowed to cool slowly; it is softened or annealed when heated and cooled suddenly. When annealing brass, care should be taken that it is evenly heated throughout and that it is evenly cooled.

Casehardening is the process of making a hardened steel case around a piece of iron. To do this the outer shell of the iron is converted into steel. The depth to which this conversion takes place varies from $\frac{1}{64}$ to $\frac{1}{32}$ inch. It depends upon the temperature to which the piece is subjected and the time during which the heat is continued. There are two methods of doing this work; the prussiate of potash and the box methods. The former is the more rapid; the latter the more reliable.

In casehardening with prussiate of potash, crush the material to a very fine powder. Then heat the steel to a red heat and apply the powdered chemical to the surface to be hardened. The powder may be sprinkled on with a spoon and then rubbed over the surface with the back of the same. The iron must be hot enough so that the potash will melt and run freely. If, during the process, the iron cools so that the potash is not kept hot, it must be put back into the fire and again brought to a red heat. It is then cooled in cold water. This process makes a very hard case: one that cannot be touched with a file. It is, however, expensive. Therefore, it is not used where a large number of pieces are to be hardened. Neither is it suited for surfaces that are large or irregular in form. When hardening with prussiate of potash the heat decomposes it and the contained carbon unites with the iron. This forms a steel which in turn is hardened when it is suddenly cooled.

When a number of pieces or one single large piece is to be hardened, the box process should be used. This is a simpler and safer method. It is more easily executed and there is not the same danger of excessive warping as in the first described process. More or less warping, however, does occur whenever a piece of iron is casehardened.

In the box process of casehardening, the pieces are packed in a box with the hardening material. The box should be of wrought or cast iron, preferably the former. It should be of such size that all of the pieces may be packed without any of them touching the top, bottom or sides. In packing, first put a layer of the hardening material in the bottom. Next put in a layer of pieces to be hardened and pack the hardening material about and over them, ramming it down. Then put in another layer of pieces and pack in the same way. Continue until the box is filled. Fasten on the cover and fill all openings with fire clay so that the box is absolutely air tight. Now set the box and its contents in a furnace where it will be subjected to an even temperature. Raise it gradually to a bright cherry red and keep it in that condition for twenty-four hours. At the end of that time, remove it from the fire, and upon opening, cool the contents in cold water.

When the pieces are taken from the water they will be found quite hard and slightly warped. They may be straightened by springing them in a press.

In this work care should be taken to place the largest articles at the bottom of the box. They should all be so packed that as they settle during the process, they will be so held that one piece does not bear unnecessarily upon another and thus cause a needless amount of warping. When cooling, put the pieces in edgewise so that the cooling may be uniform and the amount of warping made as small as possible.

Various materials are used to assist in hardening. The most common and the one that is the cleanest and least offensive is bone dust. There are a number of compounds upon the market, which are all prepared and ready for use. These usually have bone dust as a base with other ingredients added. It is better and cheaper to buy these preparations than it is to attempt to make the mixture. Excellent results can be obtained from them. Where it is desired to do casehardening, and bone dust is not available, other materials may be used. Hoofs, old leather, salt and urine make an excellent casehardening mixture. To use these materials, cut the leather and hoofs into pieces of from $\frac{1}{2}$ inch to 1 inch in largest dimensions. A satisfactory proportion will be 20 pounds of old leather, 15 pounds of hoofs, 4 pounds of salt, to which a gallon of urine may be added after the packing is completed.

Brazing. Closely allied to welding is a method of uniting iron and steel called brazing. By this means two pieces are soldered together by a brass alloy. It is used where the parts are so small or thin that they would be burned or wasted away, if they were to be raised to a welding heat. Brazing is also used where finished parts that must not be stretched or upset by hammering are to be joined. The method is very simple. The parts to be joined are made bright and cleaned of all acid or grease. Paint the parts with some flux, such as borax, and raise to the melting point of the brass. Sprinkle brass filings over the joint. The parts, to be joined, must be firmly fastened while being heated. The brass should contain enough zinc so that its melting point is well below that of the iron. It should melt when the iron or steel has come to a bright cherry red. The brass must melt thoroughly or it will not adhere to the metal. Be very careful not to get the iron too hot. The heating had best be done on a charcoal or anthracite fire. Soft coal can only be used where the greatest care is exercised. The presence of sulphur in this fuel gives very poor results.

A method that is much easier to handle is now in extensive use. A graphite crucible is used, in which a quantity of brass is melted. The parts to be brazed are brightened and fastened together in the usual manner. Then they are painted with a flux such as borax paste. The parts not to be joined are painted with an anti-flux. For this a special preparation of graphite made by the Dixon Crucible Co., will answer. When the brass has been melted and the parts prepared as directed, the latter are plunged into the molten metal and held there until they have risen to the temperature of the same. They are then taken out, wiped, and the superfluous metal filed away. This method is extensively used for brazing bicycle frames and in doing work of a similar character.

Hammers. We have up to this time dealt with those light forms of work that can be performed by hand. The greater portion of all forging work now done, both large and small, is performed with the aid of power driven machinery. The principal machines are hammers, punches and shears. In connection with these are the furnaces of special design for heating the metal.

Hammers are of three kinds commonly known as power, trip, and steam. The **trip hammer** is usually formed of a heavy beam carried on trunnions near one end. The long end of the beam is weighted with a heavy head. The hammer is raised by the action of the wiper of a cam which depresses the short arm. This raises the head. After the cam has turned so as to release the lug on the short arm, the head falls by gravity and strikes a blow upon the anvil.

The Power Hammer differs from the trip in that the speed of the head due to gravity is increased by the tension of a spring. In general form that illustrated by Fig. 73 resembles the trip. The power hammer possesses this advantage over the trip hammer, that the intensity of the blow can be varied at will. The blow of the trip hammer is always the same in intensity and is that due to gravity. It varies only in the rapidity of delivery. In a power hammer such as that shown in Fig. 73, the smith controls the intensity as well as the rapidity of the blows by a treadle. Power hammers are made of various sizes capable of doing a correspondingly wide range of work.

Steam Hammers have almost entirely supplanted trip hammers for heavy work. An ordinary form of steam hammer is shown in Fig. 74. Its essential parts are an inverted steam cylinder, to whose piston rod the hammer head is attached, and the frame for carrying the whole. The hammer is raised by admitting steam beneath the piston. The blow is dealt by exhausting the steam from beneath the piston and admitting it above the same.

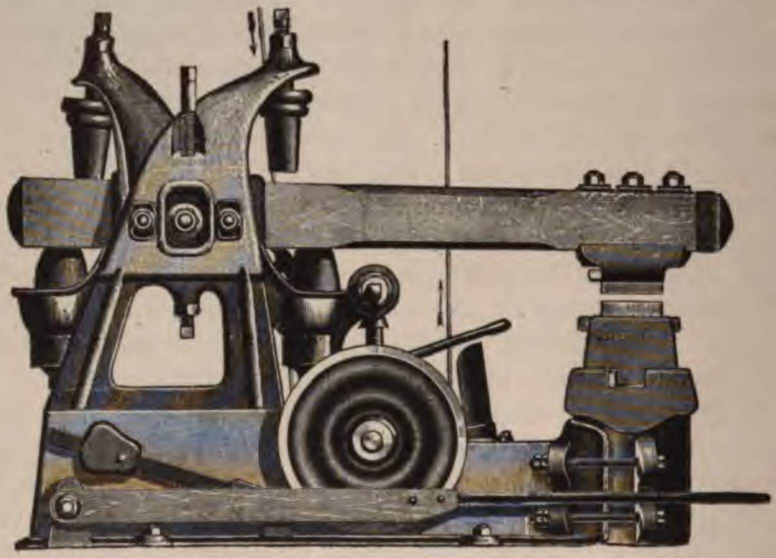


Fig. 73.

The head is thus accelerated by gravity and the pressure of steam above the piston. The valve gear is so arranged that the intensity of the blow may be varied by changing the amount of steam admitted to the piston on its downward stroke. The steam admitted below on the same stroke forms a cushion for the absorption of the momentum of the head. In this way the lightest of taps and the heaviest of blows can be delivered by the same hammer. These hammers are also made in a great variety of sizes. The head and piston of the lighter classes weigh but a few hundred pounds. The great hammer at the Bethlehem Iron Works, has these same parts one hundred and twenty-five tons in weight.

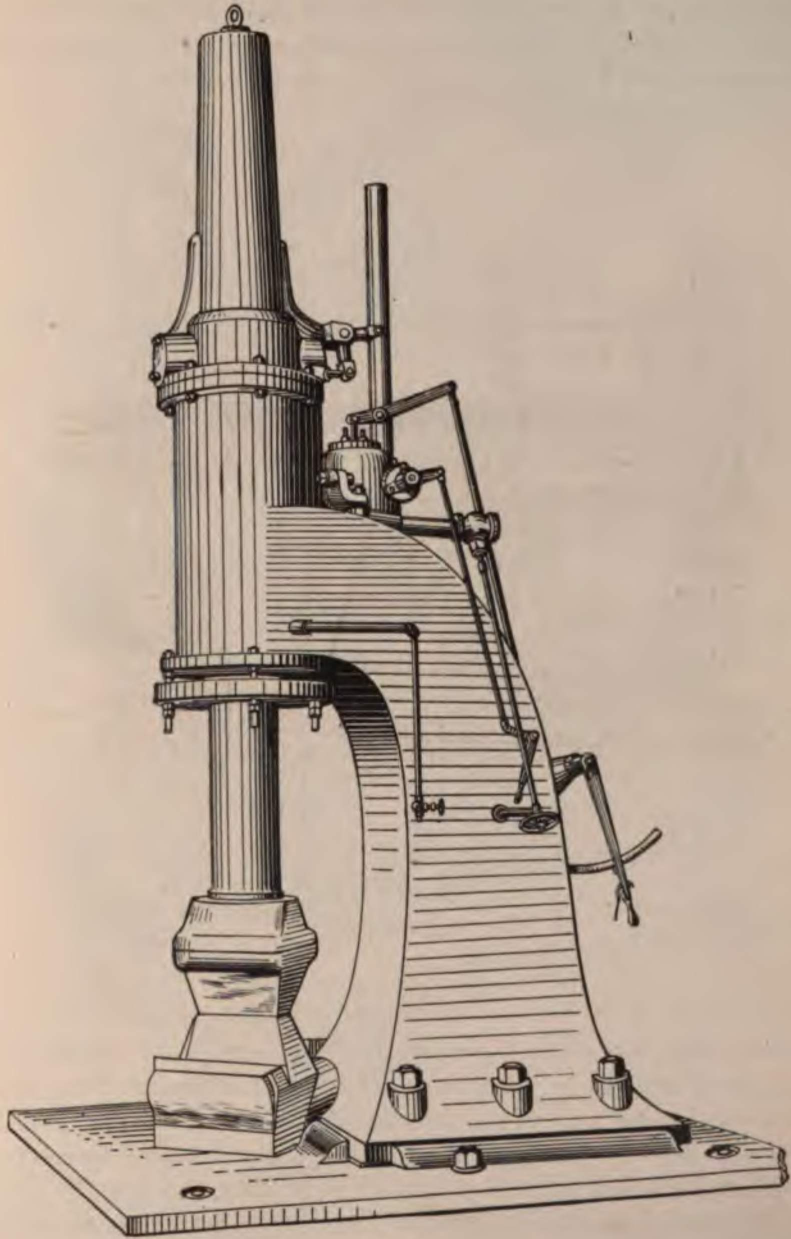


Fig. 74.

Punches are used for punching holes in metal and are of a great variety in size and design. Such a machine is shown in Fig. 75. A heavy fly wheel is kept in continuous motion by a belt of comparatively narrow width. The punch is operated directly by a cam. The connection between the two is made by means of a clutch controlled by the operator. The punch is drawn to its highest point; the work is adjusted beneath it and the clutch connection made. The energy stored in the heavy fly wheel forces the punch down and through the metal. As the punch comes up out of the metal the clutch is thrown out of gear, and the fly wheel stores the energy needed for the next stroke of work.

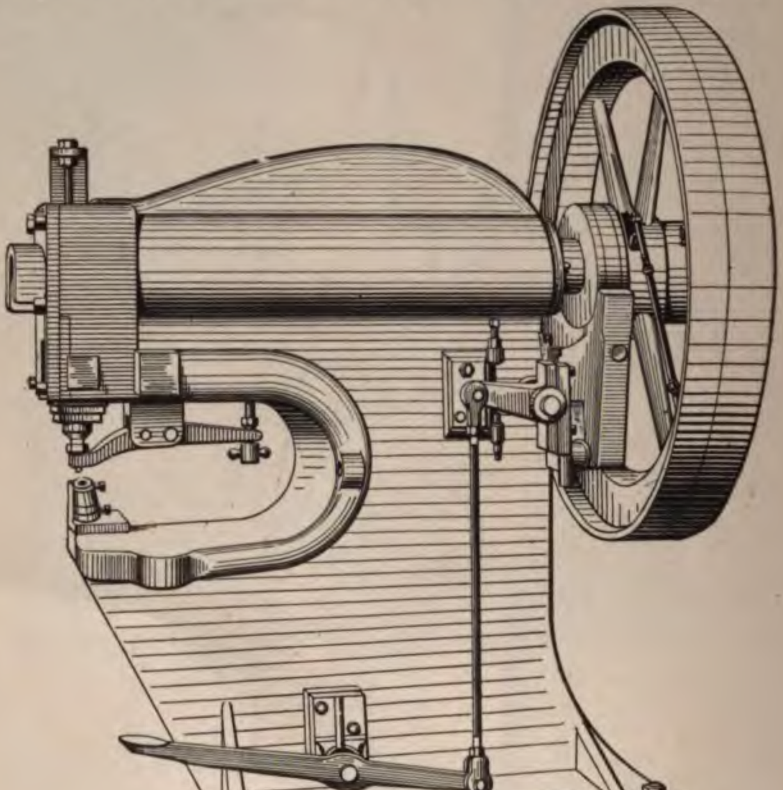


Fig. 75.

Shears are for the purpose of cutting bars or plates. A convenient and powerful form of such a machine is shown in Fig. 76. It is operated on the same principle as the punch previously described. In the actual operation of the shears, however, the clutch is not usually thrown out of gear between each successive stroke of the cutter. Where metal is being cut to length in quan-

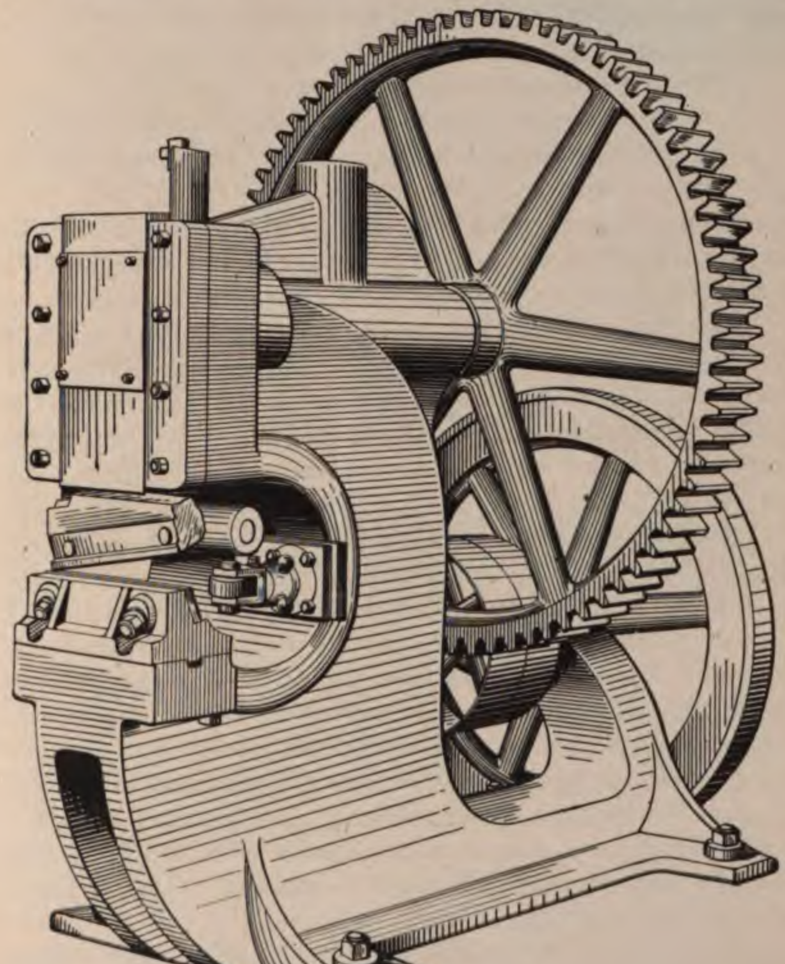


Fig. 76.

usually bolted on, back of the cutter. The iron st this as the cutter rises and is cut to uniform omes down. When shearing plates, the line of st marked with chalk, a scriber or by center punch late is then pushed between the cutter as the upper eing held there, is cut as it comes down.

many other machines of forms intended for special at are used in blacksmith shops. Among these may ed drop forges, bending machines, presses, bolt headers,

Forges are used for quickly forming complicated shapes ought iron or steel. They consist, as the name indicates, head that may be "dropped" from any desired height upon to be shaped. The head of the drop and the anvil are n of dies. As they come together the metal is forced to so as to fill the interstices and thus take on the form desired. op forging the metal must be heated to a high temperature as to be in a soft and plastic condition. A light straw color rs for most work.

ending Machines are of great varieties and are used where shapes are to be duplicated in quantities.

resses serve the same purpose as drop forges. They do the work more slowly, however. The class of work is, in some respects, the same. The principal difference lies in peculiarities of shape that require different time intervals for the flow of the metal. Where the shape is such that the metal must move slowly in order to acquire its new shape or fill the die, the press should be used.

Bolt Headers are really upsetting machines that form the heads of bolts upon straight rods. Owing to the rapidity with which they do their work, they are invariably used for manufacturing bolts in quantities.

Reverberatory Furnaces. It has been shown that for light work in the blacksmith shop the open fire either of anthracite or bituminous coal will give satisfactory results. In both of these cases the metal to be heated is in direct contact with the fuel. The same is true in the case of the cupola where iron is melted as shown in "Foundry Work." A reverberatory or air furnace is "a furnace in which ore, metal or other material is exposed to the action of flame, but not to the contact of burning fuel. The flame passes over a bridge and then downward upon the material spread upon the hearth." Such furnaces are extensively used in shops where heavy work is being executed. They are also used for melting iron or other metals. For this purpose, however, they are not economical since they require about twice as much fuel as that used in the cupola for the production of good hot iron. To be effective the flame must be made to *reverberate* from the low roof of the furnace down upon the hearth and work. The form of the roof and the velocity of the currents determines the hottest part of the furnace.

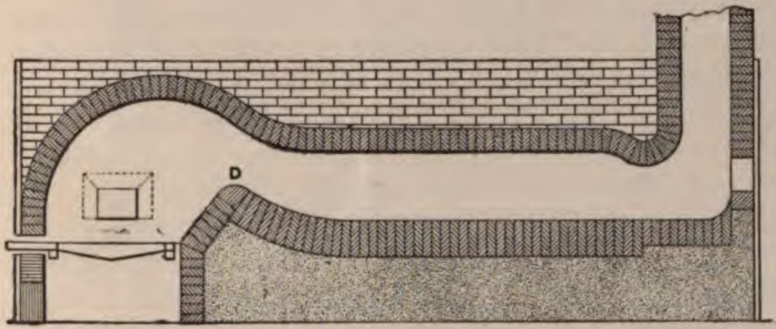


Fig. 77.

A common form of reverberatory furnace is shown in Fig. 77. The whole is lined with fire brick from the top of the grates to the top of the stack. The fuel is burned in a fire box separated from the heating portion of the furnace by a low bridge wall D. Access to the grate is obtained by suitable doors both above and below. When in service both doors are tightly closed and a strong forced draft is admitted to the ash pit. Beyond the bridge wall is the furnace proper. This usually consists of a low chamber with a level floor. Like the fire box it is completely lined with a thick wall of fire brick. Access is obtained to this chamber through a vertically sliding door as shown in the front elevation of the furnace, Fig. 78. These doors are also lined with fire brick and are usually suspended from chains. These pass over pulleys, and have counter balancing weights at the other end.

The operation of the furnace is exceedingly simple. After the fuel has been charged upon the grates, the ash pit and furnace doors are closed ; the material to be heated is put upon the floor of the chamber ; the doors are closed and the draft admitted to the ash pit. The thick walls which surround the furnace prevent radiation of its heat. The fire brick are, therefore, heated to incandescence and the hot gases sweep through the chamber. The flow of the gases is usually checked by a choke damper on top of the stack.

The outer form of these furnaces is usually rectangular. Its brick walls are tied together by stay rods to prevent bulging and the corners are protected by angle irons.

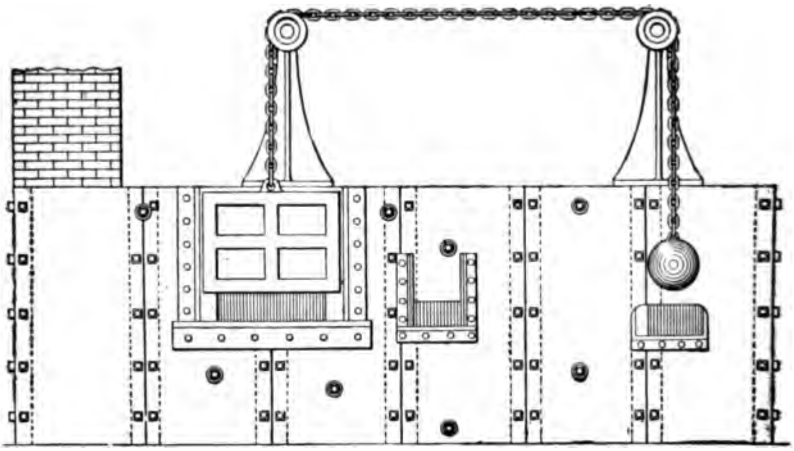


Fig. 78.

The selection of the fuel is an important matter in the operation of these furnaces. Experiments have been made with almost every kind of fuel. That now universally used is a soft bituminous coal that will not cake.

Steam or power hammers are always used in connection with these furnaces. The work is too large and heavy for manipulation by hand hammers.

An ordinary class of work done with them is the welding of slabs from small pieces of scrap. To do this a rough pine board about 12 inches wide and from 15 to 18 inches long is used. On it is neatly piled about 200 pounds of small scrap pieces. This material is then bound to the boards by wires, and the whole is placed upon the hearth of the furnace. It is allowed to remain until the whole mass is at a welding heat. When in this condition, the plastic surfaces of the pieces serve to stick them together, so that the whole mass can be handled as a single unit by the tongs. The board, of course, burns away leaving the metal on the hearth. The metal is then lifted out and placed under the steam hammer. A few light blows serve to do the welding. After this heavier blows are struck and the mass is hammered into any shape that may be desired. Usually this first hammering gives it the form of a slab. Slabs thus made are cut up and again welded to form the metal for the final shape.

In the piling of the metal upon the board or *shingle*, as it is called, great care should be exercised. Iron and steel should not be piled together. Rusty metal should be cleaned before being put in the pile. Large air spaces between the pieces should be avoided. The whole mass should be packed together as compactly as possible. It will improve the quality of the slab if the pieces are laid upon the shingle with the grain of the metal running in the same direction. This is, however, very difficult or quite impossible to accomplish.

The handling of heavy work under the hammer varies somewhat from the method employed with the light work previously described. The heavy work is all supported and moved by cranes. The ordinary method is to suspend the piece by an endless chain from a point near its center of gravity as shown in Fig. 79. This endless chain is, in turn, carried by a sheave that may be raised or lowered by the mechanism of the crane. Such a suspension reduces the labor of balancing to a minimum and permits the work being turned to suit the blows of the hammer.

If the work is so large that only a portion of it is heated at one time, it may be grasped and manipulated from the cold sections. Usually a cross-lever is bolted to such pieces, thus adding to the leverage and facilitating turning. Where the whole piece is hot it may be held by tongs of a suitable size or shape. Such tongs are commonly made with crossbars to afford the necessary leverage for turning. Sometimes the tongs are dispensed with and a *porter bar* is used. Such a bar is welded to the piece being worked to serve as a handle in its manipulation. It is cut off when the work of forging has been completed.

Connecting rods. In every shop where steam engines are manufactured the smith is called upon to forge the connecting rods. These are of great variety in size as well as in the shape of the stub ends. They are preferably forged of a single piece; but may be made from two or three. When of two pieces, the stub ends and one-half the rod are made in one piece with the weld in the center. When of three pieces each stub end and center of the rod is forged separately and then welded together. The form of the stub ends varies with the method used in fastening the brasses in position.

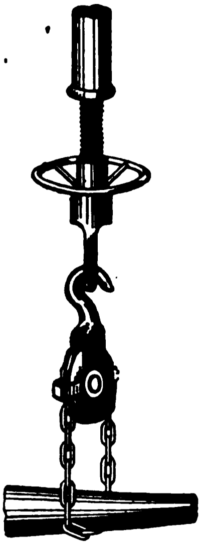
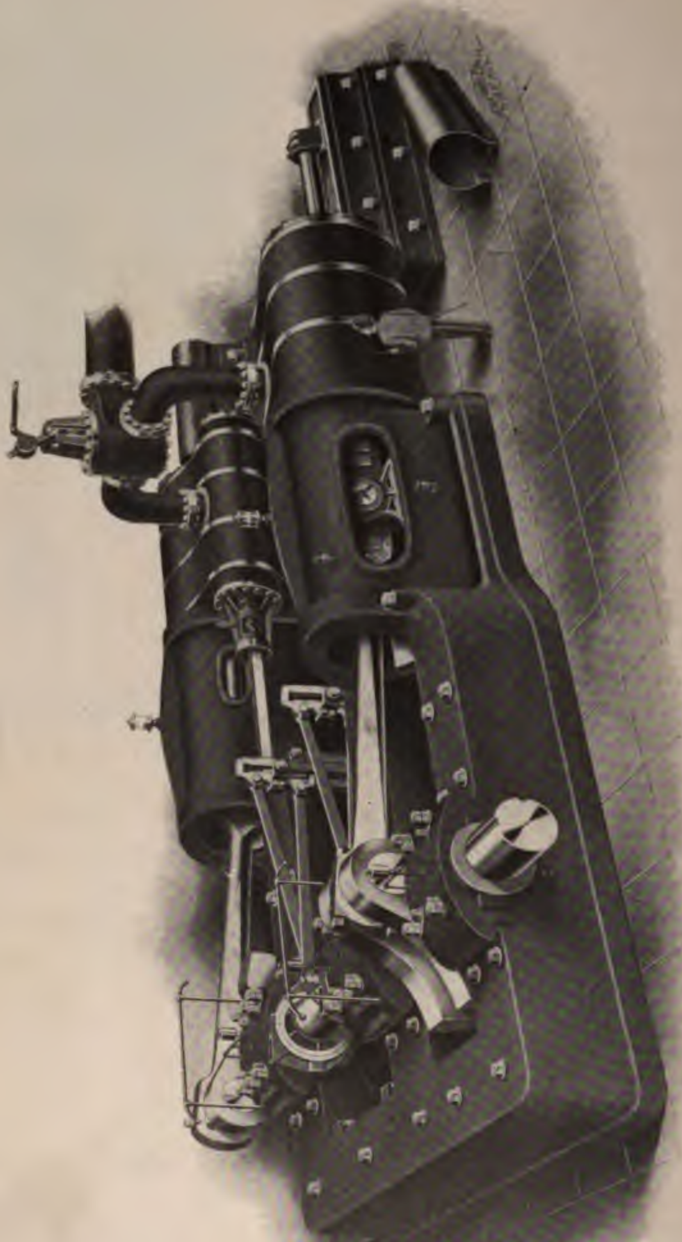


Fig. 79.

In order to forge a connecting rod of moderate dimensions, proceed as follows: Let us consider a rod having flat stub ends suited for brasses fitted with straps and keys. A block is first hammered down to a sectional area approximating that of the stub ends. It is then fullered out at H H (Fig. 80). After this has been done the central portion of the rod is drawn out to the diameter and length desired. The finished forging is shown in Fig. 81. Special care is required in the calculation of the weight of the rod's central portion : Also in the determination of weight for the corresponding section of the block and the proper location of the fuller marks H H. Unless these are properly located the proper weight or length of the rod center will not be obtained.

Shafts. The forging of shafts for steam vessels is an important piece of work and demands close attention to every detail. A most important thing for the smith to know before beginning work is the location of the bearings. He should then select his material and put it together in such a manner that no joints or welds shall occur at these points. The iron selected should be of new puddled metal, or if of steel, from an ingot newly made. If the latter is used the portion for the shaft should be cut from the lower end of the ingot. This avoids the laminations due to the



piping that usually occurs in the upper portions of all large ingots. Where steel of this character is used the work is simplified by the fact that it consists of drawing the ingot down to the desired diameter and length. When iron is used the first pile built up should be about three feet long, bound together at the ends with soft iron binders and with a porter bar set in at one end. If the furnace is large enough, the whole of the pile may be heated at once. If not, then a sufficient length to reach beyond the first bearing is welded. Three piles of this sort will suffice for a shaft 12 feet long. If the bearings are at or near the ends, this will put the welds in the central section. A suitable form of scarfing for the weld of such a shaft is that shown in Fig. 51. It is best when welding such a piece to close the joint by driving the pieces endwise. Then reheat the whole and finish the weld under the steam hammer in the ordinary manner. It is important, however, to forge the whole shaft, if possible, of one large piece. This avoids all necessity for any welds. The progressive appearances of such a shaft from the rough piece to the finished product are shown in Fig. 82. In this, A is the fagot that is first heated and to which the porter bar *a* has been welded. B represents the piece after the first hammering. It has been reduced in section in the center and made round. The ragged ends are still left in an enlarged shape. C shows the results of further hammering with a portion of the enlarged ends worked down into the body of the shaft. D illus-

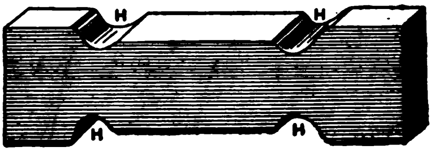


Fig. 80.

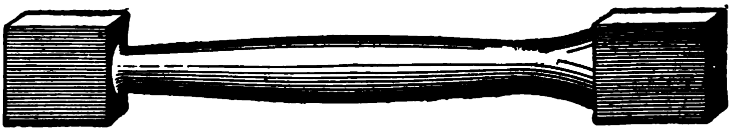


Fig. 81.

trates the completed shaft with the crop ends cut off, the ends smooth and the whole ready for the machine shop.

The working down of such a shaft as this requires constant care during each step of the process. In the first place the heating must receive close attention. The metal should be heated to a dark straw color. This should be done slowly. If the metal is taken out of the furnace after a too rapid heating, it will be found that the center is at a much lower temperature than the outside. The result of a blow delivered to metal in such a condition will cause the outside to flow over the cooler core. Such a movement will be apt to cause the metal to crack and leave cold-shuts in the body of the shaft. A *cold-shut* is a crack or space over whose surface the metal is not united. They usually occur where an imperfect weld has been formed. The action above described may produce a condition resembling a cold-shut.

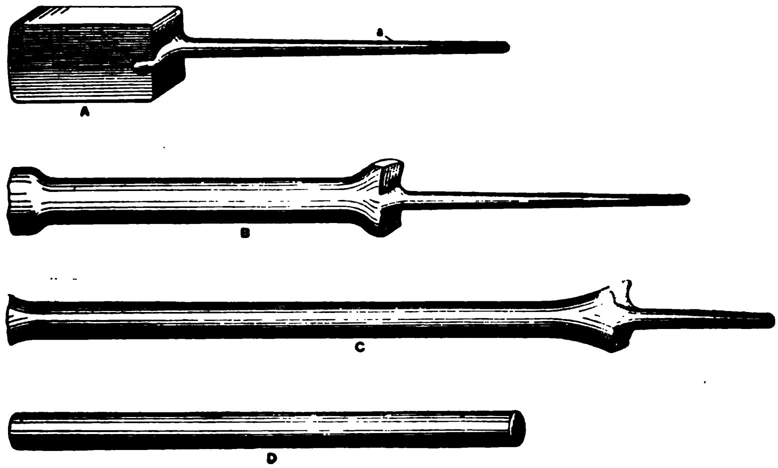


Fig. 82.

While the metal is at such high temperatures, scale forms with great rapidity. Scale, as already stated, is an oxide of iron. It can usually be brushed from the surface of the metal with perfect ease. During the process of hammering, a man should be stationed at the hammer with a longhandled brush with which he should remove the scale as rapidly as it is formed. If it is allowed to remain upon this soft and plastic material, the hammer is apt to imbed it in the body of the metal. Succeeding blows may cause the metal to flow over it, so that cold-shuts are formed.

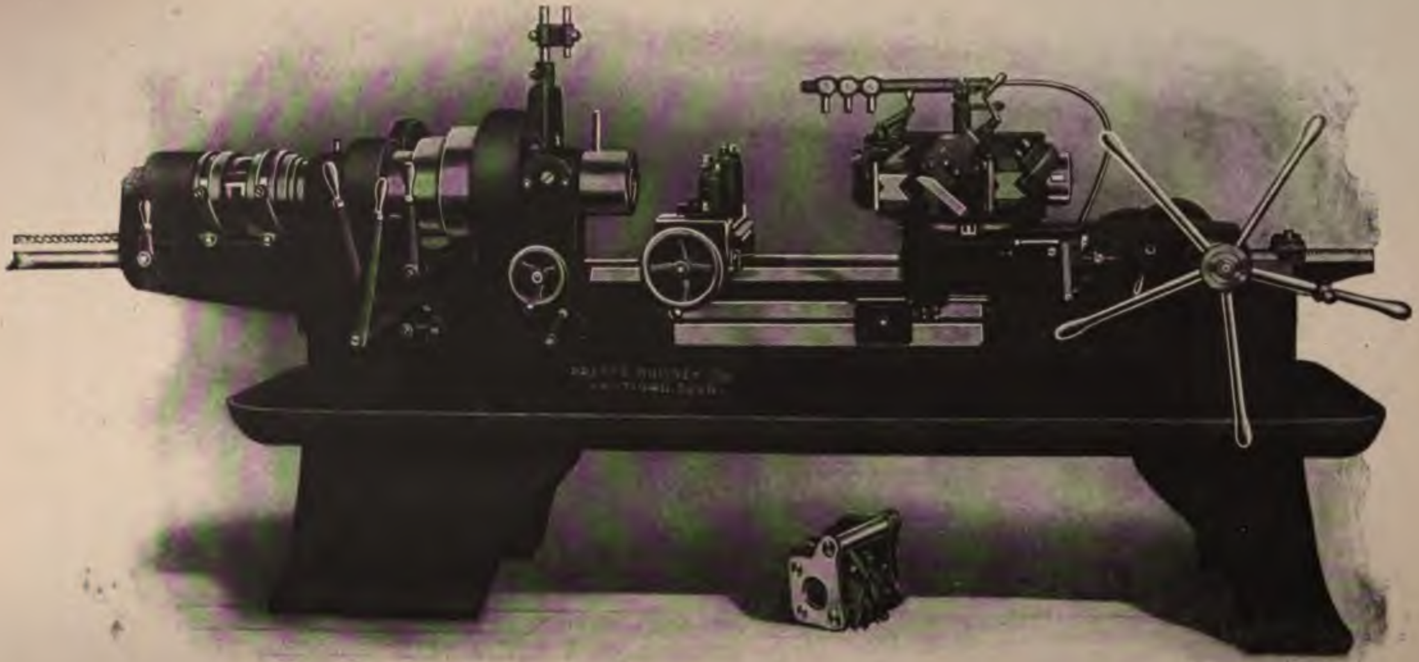
When possible, the whole piece should be heated in the furnace. Under these circumstances the hammering should be over the whole surface and not confined to any one place. If the work is evenly distributed, the metal flows evenly, and there are no weaknesses developed by distortion. But if, on the other hand, an excessive reduction is made at any one point, the hammering that must afterwards be done on the untouched section will cause a weakness, due to a distortion of the metal. If such hammering is done at the same heat the metal in the larger is worked at a lower temperature than in the first section. If the piece is reheated, the smaller section will be raised to a higher temperature than the larger and the metal at the junction of the two will probably be weakened by distortion and a flow at such unequal temperatures. In many cases the furnace can heat but one end at a time. When working metal heated in this manner, only a small amount of hammering should be done each time. The piece should be reduced gradually, first at one end and then at the other. This will prevent the formation of deep shoulders and the consequent weakening of the shaft at that point. It also avoids the wide variation in the temperatures for the different sections.

We have seen that, at high temperatures, the formation of scale is very rapid. When of a straw or light red color, the scale forms in flakes that may be easily brushed away. It is also thick and heavy. During the early stages of the forging the temperature of a heavy shaft should not be allowed to fall below a light red. As soon as it comes down to this point hammering should cease and the piece be put back into the furnace for reheating. During this early period, it is therefore, quite sufficient to brush the scale away as previously directed. As the shaft approaches completion, it is however, desirable to do the finishing work at a lower temperature. The formation of scale then becomes troublesome, as it is more and more adhesive. If allowed to remain upon the metal it may so cover the latter with an opaque coating that the piece will appear black and cold, whereas, it may actually be at a light red heat. The adhesion of the scale prevents it from being brushed away. It is, therefore, customary to turn a small stream of cold water upon the metal during the last or finishing hammering. This treatment loosens the scale, and is continued until the metal has cooled to a dark red, when the final coating of scale will form. This completely encases the body metal and serves as a tolerably efficient protection against rust.

The metal should be worked until it has been cooled to a dark red. There is a two-fold object in this. The metal is thoroughly compact and the scale is of the dark blue color that affords the most efficient protection. Care should, however, be exercised that the hammering is not prolonged until the temperature is too low. Great injury may be done to metal if this occurs. This is especially true of steel. After the red has disappeared the metal comes into what is known as the critical temperature, noticeable from the blue color. As an example of the effect of this blue temperature, which ranges from about 550° to 800° Fahr., that of boiler steel may be cited. It should be possible to bend a plate of good boiler steel double either when cold or at a red heat, without having it show any crack or flaw. If, however, an attempt is made to bend the same piece of steel when it is at a blue heat, it will crack at an angle of from 90° to 120°. Therefore steel should not be worked below a dull red heat.

The quality of a forging depends to a great extent upon the amount of work that is put upon it. Two pieces of metal may have exactly the same chemical properties and yet be entirely different in their physical characteristics. If one is rapidly forged in a single heat and at high temperature down to the finished size, it will be much weaker than another where the work has been done more slowly and by repeated heating. The work done on the metal condenses the material, adds to its strength and increases its wearing qualities. It is the investment of labor for which durability and strength are returned as a dividend.

Crank Axles. An important piece of work is the making of crank axles for steam engines either for marine or stationary service. In order to forge a small two-arm crank-shaft like that shown in Fig. 83, a soft, tenacious piece of metal should be selected, one that can be easily upset. It is well to use iron whose diameter is equal to that of the finished shaft. If the shaft is to be



2 x 26-INCH TURRET LATHE

very long it will be well to forge the crank separately and then weld it in position. First determine the position of the crank-pin by adding the length of one arm to one end of the shaft. This gives the commencement of the crank-pin. From this point to a short distance beyond the other end of the crank-pin the metal should first be upset. This upsetting should be done at or near a welding heat and should make the bar about one-quarter larger than the original diameter. The work must next be upset at the base of each arm. These points are located on each side of the crank-pin at distances equal to the length of the arm. The upsetting at these points should be such as to produce about the same increase of diameter as before. This will leave the piece in the condition shown by Fig. 84. After the upsetting the first bending should be done at one end of the intended crank-pin; the next should be at the other end. If, however, the pin is to be very short, a single bend may be used, leaving the piece in the form of a longlegged U. During the whole of this work the diameter of the crank-pin is of far less importance than the length. The latter should be so adjusted that the metal in the arms at each end will just clean up in the lathe, and leave the pin of the proper length. The only precaution necessary in regard to the diameter is that it shall be large enough. If, when the bends have been made it is found that the pin is too short, it may be stretched with the fullers. If it is too long, it should be reheated and upset.

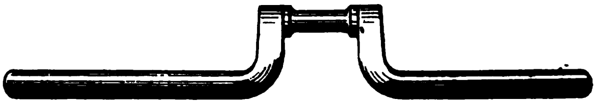


Fig. 83.

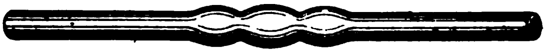
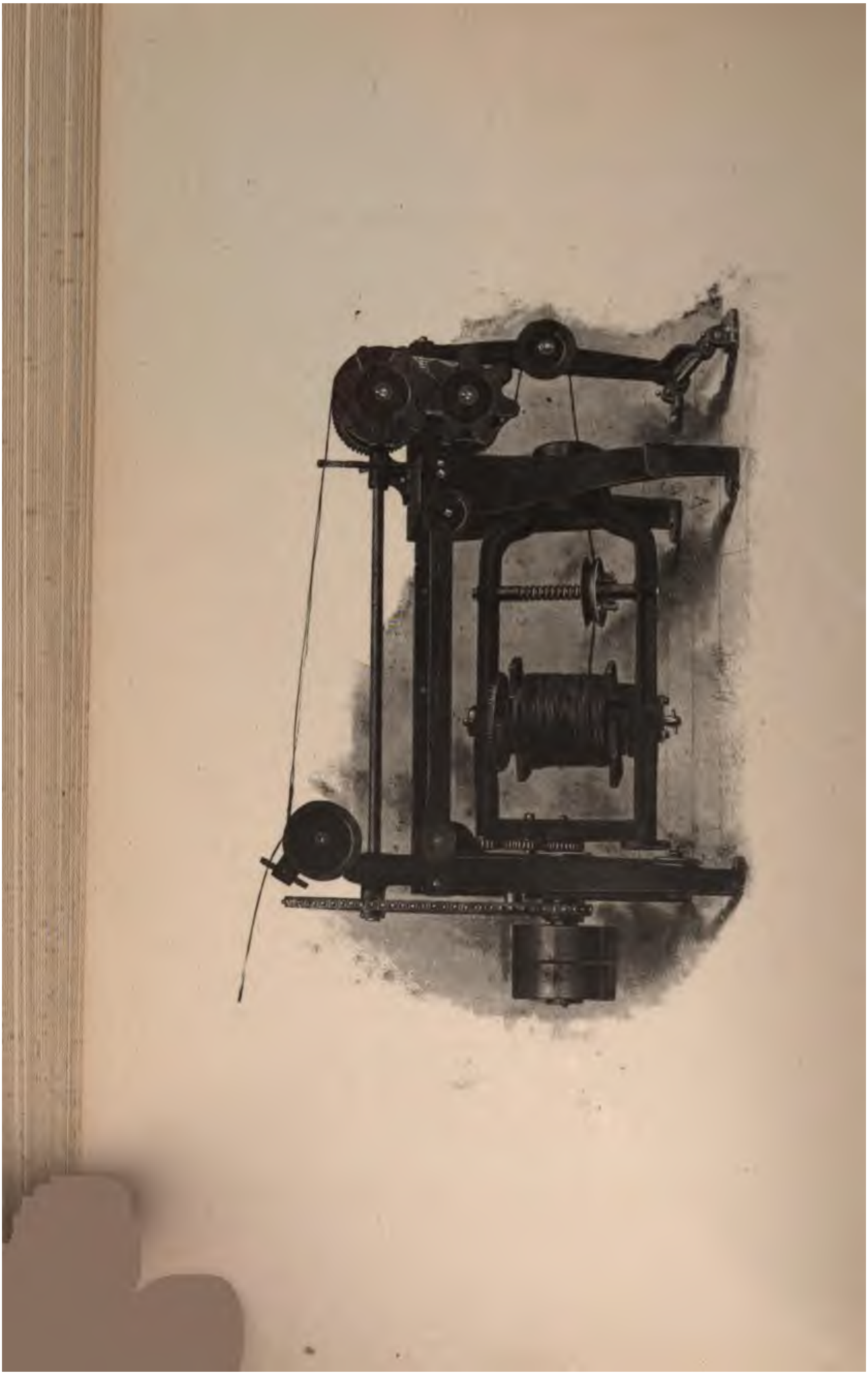


Fig. 84.

After the length of the pin has been properly formed the throw is made by bending back the two ends. This should be done when the pin is cool enough to retain its shape while the work is being done on the adjoining parts. It is well to cool the pin in water before doing the work. When this bending is of iron at 60° and at 900° is .0054 of its length when cold. Suppose then, we have the side rods of a locomotive to weld. If they are to be 9 feet long when finished, they must be 9 feet 0.58 inch long when at a red heat. This means that in the rough slightly more than $\frac{1}{2}$ inch must be allowed for contraction. If only a portion of the rod is heated the allowance is to be proportionately less.

The tempering of steel tools has already been discussed. In such work only a small portion of the metal needs to be tempered. Springs require a slightly different treatment. They must be tempered throughout their whole extent. The ordinary method of tempering a steel spring is to heat it to a cherry red and then cool it by plunging into a bath of oil. This treatment hardens the metal but does not give it the same degree as plunging into water. The reason is that the oil does not absorb the heat of the metal as rapidly as the water, with the result that the cooling takes place more slowly. Such treatment leaves the metal harder than in its annealed condition, and yet not as hard as when plunged into water. This intermediate condition is suitable for service as a spring. The best results can probably be obtained if whale oil is used for the bath.



ELECTRIC WELDING DEVELOPMENT.

The art of welding iron is probably as old as the earliest production of that metal by man; in fact, the reduction of iron in the primitive forges demanded the union by welding of the reduced particles, for no true fusion could have resulted, the percentage of carbon present being too low. Until the closing years of the last century iron was the only weldable metal, if we except gold and platinum,--too expensive for common application.

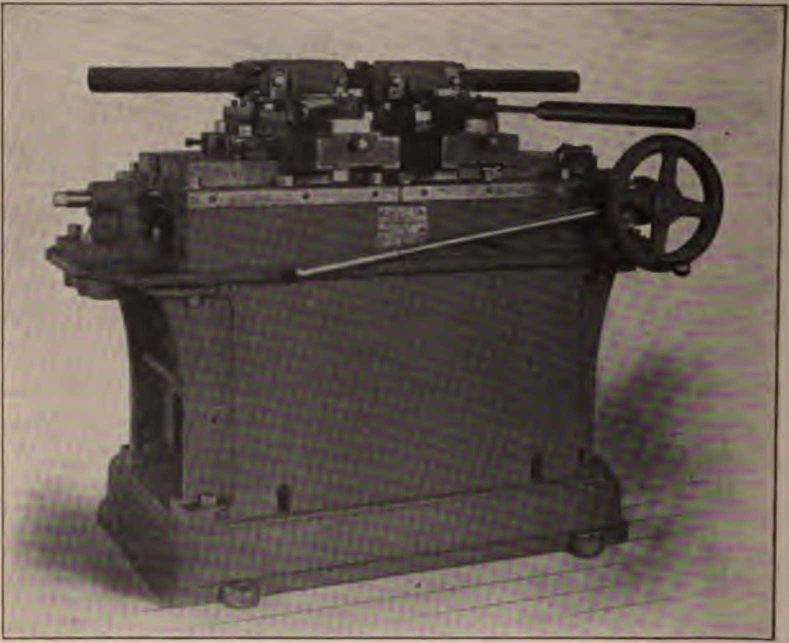
The fact that nearly pure iron, so difficult to melt, becomes quite plastic at high temperatures, while the oxide or black scale melts long before the metal itself becomes fluid, thus providing a liquid flux which is squeezed out during the process of union, accounts for the unique position which iron held until recent years. When, however, the heating effects of electric current energy, so perfectly under control, were applied to weld metals, a metal or alloy which would not weld became the exception, instead of the rule, as before. Much of the former work of the smithy fire is now accomplished by the electric welding transformer, and although many metals are easily manipulated by the electric process, iron, of course, still occupies, as ever, the principal place.

The electric weld is becoming a more and more important factor in many industries. During recent years the extension of its application has been steady, and each year has witnessed its entrance into new fields. Sometimes, indeed, new manufactures, or new ways of obtaining results have been based upon its use. The electric welds under consideration are the results of that operation of uniting two pieces of metal by what is known as the Thomson process, first brought out by the writer and rendered available in commercial practice a considerable number of years ago. The rapidity, flexibility, cleanliness, neatness, accuracy, and economy of the electric process has won for it such an important standing in the arts that many future extensions in its application are assured.

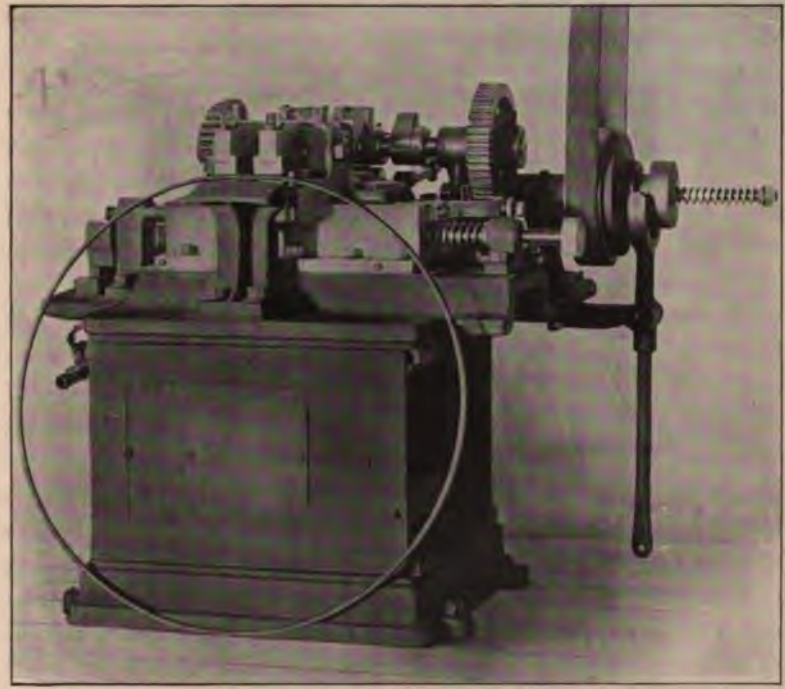
NOTE: **This article by Prof. Elihu Thomson, the inventor of the system of Electric Welding, first appeared in Cassiers' Magazine, and is here reprinted by special permission.**

The uniformity of the work, the control of the operation, the extreme localisation of the heat to the particular parts to be united, and the fact that the process is not limited to iron and steel, but can deal equally well with other metals, such as copper, brass, bronzes, and even lead, are characteristics of the electric welding operation.

The Electric Welder. In its simplest form, an electric welder consists of a special transformer, the primary circuit of which receives current from an electric station or dynamo generator, at a voltage usually from one hundred to five hundred times that required to make a weld. The copper secondary circuit of the transformer is generally only a single turn of very large section, so that it may develop an extremely heavy current at from two to four volts,—an electric pressure so low that it cannot give the least effect of shock, and one for which there is no difficulty in securing perfect insulation. The work pieces are held in clamps or vises, attached to or carried upon the terminals of the



ELECTRIC WELDING MACHINE FOR IRON AND STEEL PIPE.



ELECTRIC TIRE-WELDING MACHINE.

single-turn secondary circuit. The control of the clamping devices and the current switch is either manual, or, in some cases, entirely automatic. Without attempting to enumerate the many applications of electric welding in the arts, we may refer to a few examples.

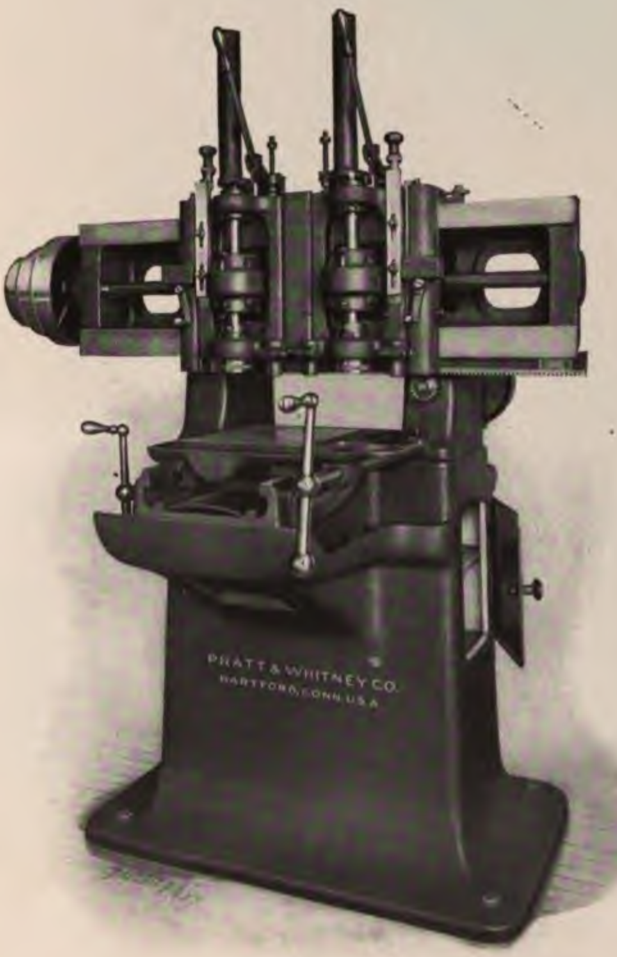
Applications. In the waggon and carriage industry the process is applied in the production of tires of all sections, axles, hub, spoke and sand bands, fifth wheels, shifting rails, steps, shaft iron, etc., while it has found a large use in the welding into continuous strips or bands of the wires inclosed in rubber tires for holding them in place. The larger part of the dash-frames used in carriages in the United States are now probably made by electric welding, while iron and steel agricultural wheels are built up, or have their parts united, by electric welds.

To enumerate the many applications to the bicycle industry would be almost to catalogue most of the metal parts of this useful machine. It must be borne in mind, too, that a welding machine, slightly modified, is equally applicable for locally heating parts in electric brazing or hard soldering, for upsetting, and for bending or shaping. Bicycle crank hangers, pedals, seat-posts, fork and fork ends, frames and brake parts thus become products in which the welding transformer has its part. It has found a useful field also in tool manufacture, such as drills, reamers, taps, band and circular saws, drawing knives, carpenter's squares, printer's chases, etc., etc., and electric welding has a closely related use in the production of machine parts. Cam shafts and crankshafts are made from drop forgings welded together, teeth are inserted into gear wheels, and teeth are welded to saw bodies, including stone saws. Such things as inking rolls in printing machines and fallers for looms are additional examples.

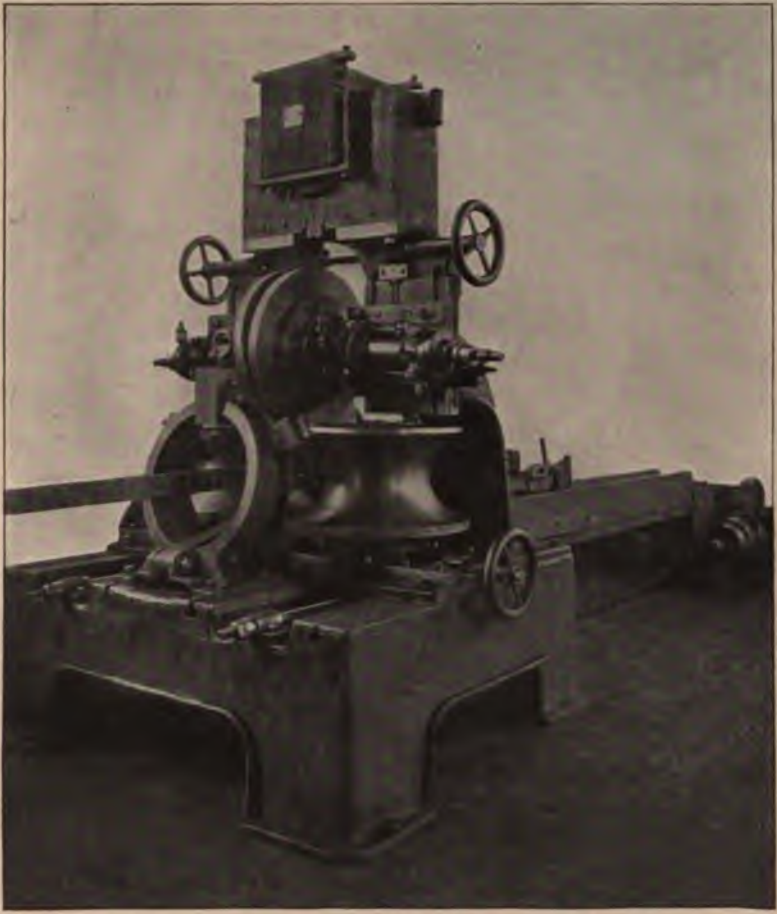
In the wire industry the part played by electric welding is already quite important, and becomes steadily more so. Besides the mere simple joining of wires of iron, steel or copper into long lengths, the welding of wire or strip into hoops for barrels, tubs, pails, etc., is supplanting the older forms. Numerous machines are in operation turning out electrically-welded wire fence, much as a loom turns out cloth. In pipe bending and coiling, as in uniting ordinary lengths of pipe into very long lengths without screw joints, the electric weld has a special adaptability. Hundreds of miles of street railway rails have been welded into continuous lengths and now exist in many cities. Where rails are bonded only, the electric welder assists in the production of brazed or welded bonds.

It is a wide range between buckles, typewriter bars and umbrella rods to the local annealing of armour plates on warships, but the electric welder covers that range. It is no wider, however, than that from fine wires of a diameter of one-fiftieth of an inch up to heavy steel wire for the armour of submarine cables, and again up to street railway rail joints.

In recent years, elaborate machinery, for the actual production on a large scale of steel tubing from flat stock or skelp by the progressive welding of a longitudinal seam, has been put into operation. The long strip, or skelp, is rolled up so that its edges meet. In this condition it enters between the welding rolls, which



TWO-SPINDLE PROFILING MACHINE.
Pratt and Whitney Co.



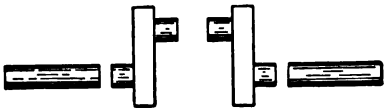
WELDING MACHINE FOR LARGE TUBES OR SHELLS UP TO 16 INCHES IN DIAMETER.

pass the heating current locally across the edges to weld them, and the operation is progressive from one end of the pipe to the other as it is fed into the machine. The result is a pipe of which the walls are of even thickness and the diameter uniform. This pipe can be afterward drawn, if needed, to the exact size desired. Very thin pipe can be made of steel, the longitudinal seam or weld in which is a delicate bead along the length,—a beautiful product, for the extreme localisation of the heat has allowed preservation of surface and finish of the metal outside the joint. Taper tubes, such as are used for bicycle front forks and the like, are easily made.

A similar machine for large work has lately been constructed, and by its use large diameter tubes or shells, up to 16 inches in diameter, are produced from sheet steel or iron. The accompanying illustration shows such a machine ready for operation. The welding transformer is at the top of the machine, and the secondary circuit has for its terminals two copper rolls inclined to each other on two nearly horizontal shafts adjustable in position over the work. Below are the guide rolls, one on each side on vertical shafts, and between these the shell to be welded passes with its meeting edges uppermost and in contact with the copper contact rolls. As the metal shell passes along under these rolls the joint is progressively heated by the welding current crossing it, and the weld is finished by the side pressure of the guiding rolls. The process, as well as the resulting welded product, is unique.

For a considerable time past, welding machines have been applied to the production of bands or tires from stock of varying width, thickness, and sectional form. More recently the practice of welding plain bands or cylindrical rings, and afterwards rolling them with the form of section desired, has been largely adopted; such as, for example, in the production of automobile wheel rims, bands for roving cans, stove rings, etc.

Very different from this is the formation of crankshafts, now demanded in great numbers for engines of automobiles. These are made from drop forgings and round shaft stock by uniting the pieces, as in the annexed sketch, and afterwards lightly machining and finishing the approximately correct shaft, as produced by welding.



Besides the banding of wire or strip of such comparatively frail containing vessels as barrels or pails, the electric weld finds application in the forming and capping of metal vessels for withstanding high pressures, such as soda-water cylinders, carbonic acid reservoirs, and steel bottles for nitrous oxide gas.

One of the most interesting of the more recent applications is that of welding hollow steel handles on cutlery, such as table

ELECTRIC RAIL WELDING ON STREET RAILWAYS.

knives and forks. The operation is remarkable for the celerity and neatness of the work, the articles being finished by silver-plating and polishing, as usual. The hollow handle is drawn from thin steel, and united to the knife blade or to the fork, as the case may be, in a special welding machine, there being no brazing or other operation of joint-forming required. There is, indeed, no limit to the delicacy of the work which may be undertaken, provided only the welding apparatus is equally refined.

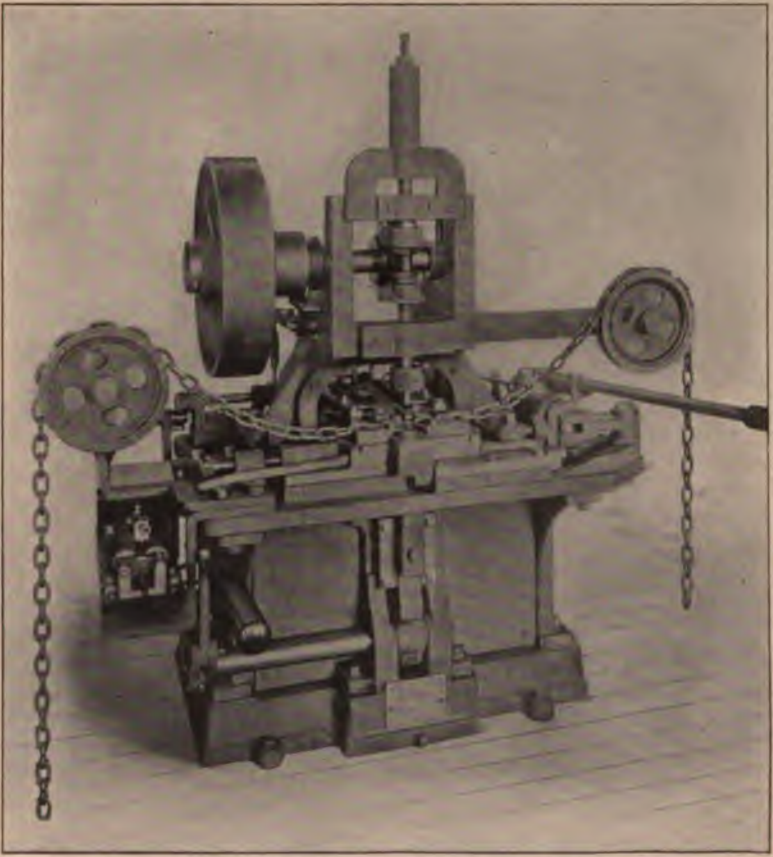
Adjustments. In the simpler types of electric welders, especially where the machine is designed to do a variety of work, perhaps of different forms or sizes of pieces, or both, the adjustments are usually manual; that is to say, the operations of clamping the pieces and applying the electric current and mechanical pressure are each controlled by the operator. In other cases, such as in the welding of copper or aluminium wire, the machine is, at least in part, automatic. The pressure is automatically applied and the welding current is cut off automatically upon the completion of the joint; the placing of the pieces in the clamps and the switching on of the current is, in this case, manually performed.

In other, more completely automatic, types, particularly adapted for rapid repetition of the same operation on identical pieces, the machine runs continuously, and its sequence of actions is definitely determined by the construction. In such cases a source of power, as by a belt, drives the machine, the movement so imparted having the effect of clamping the pieces as they are fed to the machine, putting on the current, applying the pressure, cutting off the current and releasing the pieces.

The mechanism which has been developed for these purposes displays, in many instances, much ingenuity. In these machines the duty of the attendant is limited to the mere placing of the pieces between the clamping jaws, just before they are clamped, and the work is characterised by rapidity and by uniformity of the results.

More completely automatic still are machines for the production of wire fencing and for the consecutive welding of the links of chains. In these the operation, once started, goes on uninterruptedly so long as the work holds out, or until the stock undergoing operation is exhausted. In the fence machines, of which fifteen are now in existence, galvanised iron wires are fed from reels parallel to one another, at distances apart depending on the mesh desired. These may correspond to the warp in weaving. Transversely to these, and at intervals corresponding to the mesh selected, are fed wires, cut from a reel, which transverse wires are the verticals in the finished fence itself and correspond to the weft in weaving. A series of small welders are automatically brought into operation to weld each transverse wire to the longitudinals where the two cross. This done, the web so formed moves forward, the operation repeats itself, and so on continuously. The welding is, in this case, practically instantaneous, and all of the movements of the machine are entirely automatic.

In this way it is possible for a single machine to turn out many thousands of feet of fencing per day with a width of mesh from 2 or 3 inches up. Less wire is used than where the joints are made by twists or loops, and the stability or fixedness of position of such joints as are made is much more assured.



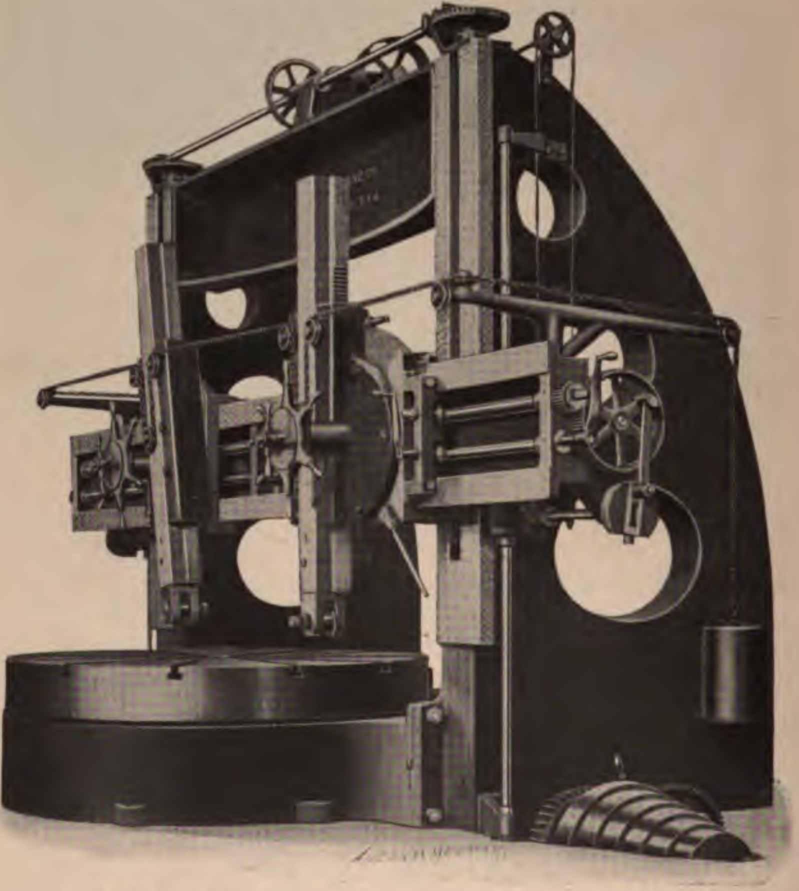
ELECTRIC CHAIN-WELDING MACHINE.

Joints. While in most cases of electric welding the joint forms what is known as a butt weld, with a burr or extension of metal at the joint, which, according to conditions, is either allowed to remain or is forged down or dressed off, there is no difficulty in making lap welds electrically, and some of the recent work of the electric welder is of that character. While, too, the usual welding concerns pieces of the same metal, as iron to iron, steel to steel, or copper to copper, combination welds of different metals are made with facility in many cases, as when brass and iron are united.

In the working of high-carbon steels the usual precautions to prevent burning or injury to the metal are, of course, required; but, on account of the delicacy of heat control, they are more easily adopted.

ROLLS OF ELECTRICALLY-WELDED WIRE FENCE.

Quite recently automatic chain welders have been put into use, and electrically-welded chain work will probably soon attain an importance not second to the other principal applications which have been briefly described.



EXTRA HEAVY 10-FOOT BORING AND TURNING MILL.
Betts Machine Company.

THE IDEAL FOREMAN.

Qualifications Requisite for His Highest Success.

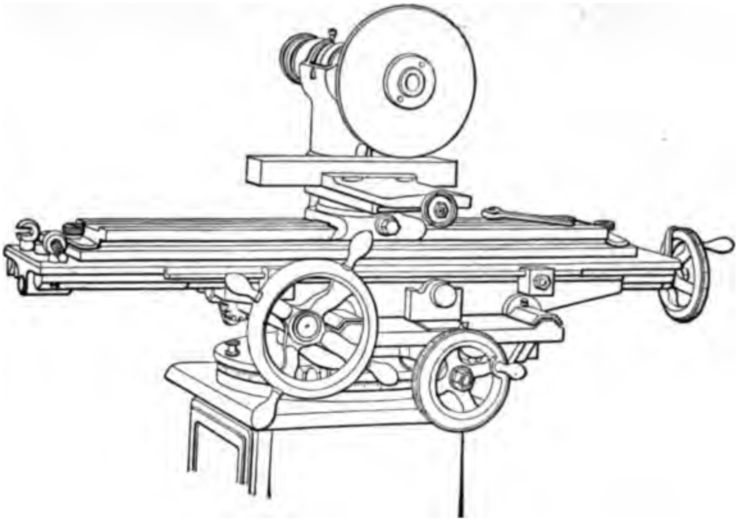
Any attempt to outline an ideal is apt to be met with many differences of opinion, if not actual denials. One reason for this difference of opinion is found in the fact that ideals are always on a sliding scale The ideal of to-day becomes the realization of to-morrow, and the point of view depends upon how far up the ladder of idealism the observer has advanced. To borrow an illustration from the shop, probably every workman remembers that on entering the factory as an apprentice, his boyish ambitions were centered on advancing to a position occupied by some workman well up the line, who, in the opinion of the apprentice, was better dressed and had an easier task than his fellows. In the course of time, if the young man was ambitious and persevering, he probably occupied this or a similar position, and then found, to his dismay, that his ideal had changed, and that he now looked forward to occupying the position held by the foreman or superintendent. In other words, viewed from the point of attainment, an ideal is a will-o'-the-wisp, always keeping just beyond our reach. It is well that this is so, for there is no human failure so complete as the man who is entirely satisfied with himself.

From another point of view the ideal is a movable feast, because, to quote an example from our subject, the ideal foreman of the apprentice is not that of the skilled mechanic, while the views of the owner on this subject are almost sure to be at variance with those of any of the workmen. We can readily appreciate how the bright boy idealizes the man who treats him kindly and who gives him an opportunity to learn. The lazy boy feels kindly disposed toward the foreman who gives him an easy task. The poor and careless workman wants a foreman who will pass work which is not a credit to the craft, and who is blind to the evils of laziness and, possibly, to those of the drink habit. The skilled workman asks nothing of a foreman but to be treated like a man, to be given a proper share of the desirable work, and to be allowed to work out his own salvation along these lines. The owner looks to his foreman to make money for him. In many cases, he expects him to make more money than the capital invested and the methods pursued will warrant. This means that the foreman is expected to crowd the workmen to the limit, and to keep both the plant and the help as near the breaking point as it is possible to carry them. Some owners and managers, however, are content with a reasonable return on their property, pursue up-to-date methods, and give to the workmen some thought beyond their mere capacity to earn dividends. It is to be regretted that men of this type are not more often found in positions where their humane policy can be held up as an example to those of a more sordid and grasping nature.

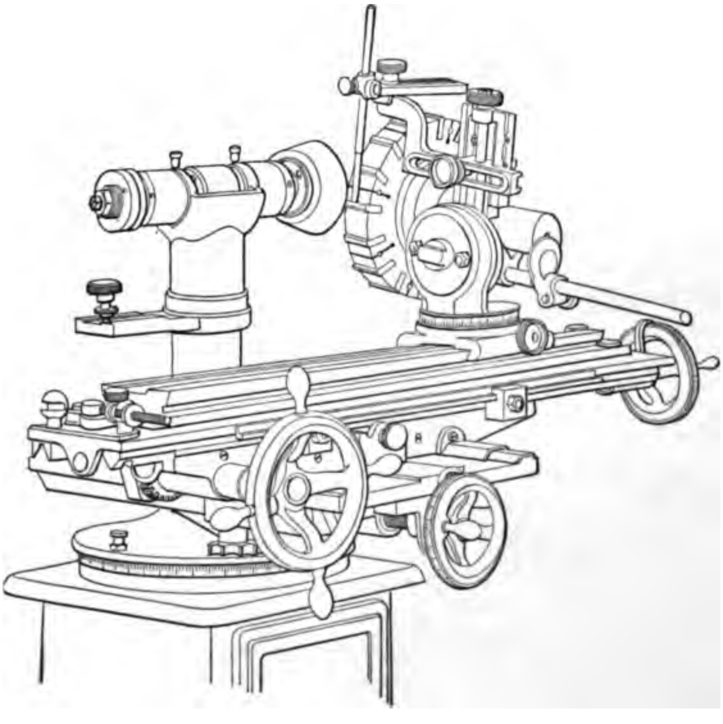
It having been shown impossible to outline an ideal foreman, when viewed from these different standpoints, evidently the discussion of what a foreman should be can be no more than a statement of the personal opinion of the writer.

Before all other qualifications, it is necessary that the foreman should be what the word implies—first, a man; and, second, a leader. If he is a man in the true sense of the word, he cannot fail to be respected by all self-respecting workmen. If he is an honest leader, he will conduct those workmen along the lines laid down by the owners as the policy of the establishment. Too often the foreman is looked upon merely as the buffer between the firm and the men. He is supposed to act as peacemaker, and to keep them from flying at one another's throats. Under such conditions, it is obviously impossible that a man can be in full favor with either party. Toward the firm the foreman should be respectful, obedient, and energetic; toward the workmen he should be firm, just, and sympathetic.

Of all the qualities going to make the ideal foreman, that of tact is the most important. It means that the men will be treated as individuals, their failings noted and corrected, their good points enlarged upon and due credit allowed for them, and that the shop life will be freer and more natural. With this tact, or faculty of governing along the line of least resistance, must be coupled absolute fairness. Nothing will create such an atmosphere of discontent as a suspicion that the foreman has favorites. If these supposed favorites happen to be relatives of the foreman, the idea is much harder to combat. For that reason, personal friendship



UNIVERSAL VISE ARRANGED FOR SURFACE GRINDING.



SHARPENING TEETH OF LARGE FACE CUTTER.
Norton Emery Wheel Co.

and family obligations will be left outside the shop by the man who wishes to succeed as a leader of workmen. A decided, but not aggressive, manner of passing upon questions serves to inspire the men with respect for the foreman, especially if such decisions are rendered promptly, and they prove in the large majority of cases, to be accurate. Having made a decision, or taken a decided stand on any matter, it will not do to deviate from that position, unless it is so clearly wrong as to be apparent to the casual observer.

Fairness, dignity, and firmness are qualities that can be quite closely defined; but tact and its fellow attribute, executive ability, are rather elusive of close description. They are of the inherited type and can be cultivated only to a very limited extent. If a man does not possess tact and executive ability, it is useless for him to accept a position where they are essential, in the belief that they will develop as required.

While workmen are supposed to be paid only for the time spent in the shop, it is also true that a man's value cannot be reckoned entirely by the quality of his work and the number of hours of labor. His conduct outside the factory invariably leaves its impress on his conduct within and on the product of his work. This is even more noticeable in the case of a foreman, for, although workmen generally would deny it, they do not and cannot have a wholesome respect for a foreman who is not respected by the community. Men will say they do not care what a foreman is outside the shop; but their better nature will not allow them to look up in any sense to a social pariah.

While an absolute grasp of all the details of the business, viewed from the workman's standpoint, is not absolutely necessary to a foreman possessing tact and executive ability, it adds greatly to a foreman's prestige to be able literally to show any workman just how any operation should be performed.

Just a word in illustration of tact in dealing with men of radically different temperaments. The blustering workman, so familiar to all foremen, can be best controlled by a very quiet and soft-spoken superior, especially if the foreman in question has the reputation of firmness and fair dealing. The quiet, positive statement, coupled with a refusal to discuss the matter, is so contrary to the blatant workman's usual procedure, that it takes away his only weapon by not allowing him to use it. On the other hand, it often happens that the quiet man of few words can be spurred on to better deeds by an energetic and insistent manner on the part of the foreman. Of course, this all goes to prove the foreman's tact, and to disprove the oft-repeated statement that workmen should all be treated alike. The best results cannot be obtained in this manner. Until men are all turned out in the same mould, it will be necessary to suit the treatment to the temperament of the man.

The question of how far it is advisable to show sympathetic nature, is one of grave doubt. Sympathy does not mean that excuses are to be taken literally; but a casual inquiry as to how the sick wife or baby is getting along shows an interest outside the commercial relation that appeals to most men. The old saw, " You catch more flies with molasses than you do with vinegar", has an application in the treatment of workmen by their foreman.

Another question which has more than one answer, is whether it is better to have a foreman promoted from the ranks or to get an outside man for the position. The man from the bench is familiar with all the shop traditions and practices, and can keep things going with hardly a break. On the other hand, he is the victim of jealousy and spite, and, unless exceptionally well-poised, is apt to assume an attitude toward his former shopmates which might be termed "dignity gone to seed". Every youthful indiscretion is remembered, and any attempt to check such antics on the part of the younger men is held to be an unwarranted assumption of dignity. On the whole, the attempt to promote a foreman from the floor or bench is fraught with difficulties; and many a man who would have made an excellent foreman in another shop, has been a rank failure in that capacity when tried among his old shop associates. The foreman taken from the outside stands or falls, as far as the workmen are concerned, on his record in his new position. He is not condemned for past faults. Furthermore, he should be able to bring into his new associations some of his experience in former situations which will be of value to his new employers. It is an infusion of new blood and is often the means of discovering leaks and weaknesses not noticeable to the old employees.

A foreman's value to a firm depends largely on his knowledge of the capacity and limitations of each man under him. This knowledge enables him to lay out his work to the best advantage, as he knows the man who is quick, the man who is accurate, and the man who can be trusted to carry along detail or experimental work. To keep a man up to his best pace, to have new work laid out for him in advance, and to keep that man satisfied with his work and wages, is a task that taxes the ingenuity of the best of foremen. The matter of repairs, especially those of a petty nature, is one which tests a foreman's commercial sense more than the regular run of work does. As an example, suppose that the friction on a countershaft slips; shall the oiler be sent for while the machine operator waits; shall the workman fix it himself; or shall the man be transferred to another machine while the repair work is going on? Of course, this all depends on the nature and degree of the difficulty; but it affords an opportunity for quick and accurate judgment on the part of the foreman, and demonstrates his fitness to cope with emergencies.

An article of this character should not be closed without a reference to that old-time figure, the "working foreman". Do not all machinists of mature age remember how the foreman would walk down the shop with a piece of work and a file in his hand, filing as he went? Even in these days of strenuous competition, we sometimes see an advertisement for a "working foreman". It is preposterous to think that a foreman can properly supervise the operations of more than a dozen men, and do any work that calls for close attention. Many firms insist on this practice, however, and are daily losing money by its continuance. A foreman should be devoting his energies to the development of better methods of manufacture, and not to the production of work that could be performed by one of the machinists.

And so we leave the ideal foreman, not yet discovered, not even closely defined, but anxiously awaited and badly needed.

REVIEW QUESTIONS.

PRACTICAL TEST QUESTIONS.

In the foregoing sections of this Cyclopedia numerous illustrative examples are worked out in detail in order to show the application of the various methods and principles. Accompanying these are examples for practice which will aid the reader in fixing the principles in mind.

In the following pages are given a large number of test questions and problems which afford a valuable means of testing the reader's knowledge of the subjects treated. They will be found excellent practice for those preparing for College, Civil Service, or Engineer's License. In some cases numerical answers are given as a further aid in this work.

REVIEW QUESTIONS

ON THE SUBJECT OF

MACHINE DESIGN.

The drawings made in accordance with the problems below should be traced in ink on tracing cloth 18 by 24 inches in size, and having a border line ½ inch inside the edge of the paper.

PROBLEMS.

1. Suppose a 30-inch pulley is substituted for the 42-inch in the problem given, and that the pulley on the motor remains 10½ inches as before, how fast must the motor run to give the rope the same speed, 150 feet per minute?

2. Will the horse-power of the motor be changed with this new condition? Explain fully.

3. Calculate the width of double belt for above condition.

4. What is the torque on the motor shaft for above condition?

5. Calculate the size of shaft in the small pulley for above condition.

6. Calculate the size of shaft in the 30-inch pulley for above condition.

7. Design and draw both pulleys for above condition, making complete working drawings, and giving all calculations in full.

8. Taking the original problem as given in the text, suppose it is desired to increase the large gear to 45 inches diameter, calculate the load on the tooth, and a suitable pitch and face to take this load.

9. How many teeth must the pinion have to give the same speed of rope, 150 feet per minute, assuming that the motor runs 470 revolutions per minute, for condition in Problem 8?

10. Calculate the bore of pinion for this case.

11. Design and draw the gears for the conditions of Problems 8 and 9, giving all calculations in full.

12. When there is but 3,000 pounds on the rope, what are the tensions in each end of the brake strap, assuming that the size of drum and other conditions remain the same?

13. How much pressure on the foot lever would it take to hold this load of 3,000 pounds on the rope?

14. Suppose we put a bearing 9 inches long on the drum shaft; the distance, center to center of bearings, would then be 3 feet 8¾ inches, gears, drum, brake, and load being same as in the original problem of the text. Calculate the diameter of the drum shaft.

15. Suppose the height of bracket, center to base, to be 15 inches; length and diameter of bearing, as in Problem 14; and that we use a separate bracket for the drum bearings, not connected with the pinion-shaft bearings. Design and draw such a bracket.

16. Calculate, design, and draw all the parts for a machine similar to that of the text, from the following data:

Load on rope	4,000 pounds.
Speed of rope	175 feet per minute.
Length of rope to be reeled in	250 feet.

NOTE. Problems 12, 13 and 15 are comparatively simple, following closely the steps of the text in their solution.

Problem 16, likewise, is supposed to be worked out on the same lines as the text, but is wholly original in its nature, being based on entirely new data. It is not expected that this problem will be attempted except by well-advanced students who can give considerable time to working it out completely. It will be found, however, an excellent exercise in original and yet simple design.

REVIEW QUESTIONS

ON THE SUBJECT OF

PATTERN MAKING.

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1. What are some of the causes of warping in lumber?

2*a*. When is metal used for patterns?

2*b*. Why is metal better than wood?

3. Why should plenty of oil be used on an oil-stone?

4. Explain with sketch the method used in casting a small hollow cylinder.

5. For what parts of the pattern must the shrinkage rule be used?

6. Is the draft always the same on all parts of a pattern?

7. What is the usual allowance for finish on small castings?

8. When must a greater amount be allowed?

9. Under what conditions will a seasoned board warp?

10. What wood is most commonly used in pattern making?

11. Explain the difference in the manner in which saws cut when ripping and when crosscutting.

12. In what direction should the grindstone revolve when grinding scraping tools or other tools having a short bevel?

13. When is dry parting sand used?

14. Should a shrinkage rule be used when making a core box?

15. Why must the pattern maker know something of Mechanical Drawing?

16. When it is necessary to use a wide piece for a pattern, how may the tendency to warp be counteracted? Make sketch.

17. Explain the use of the cap-iron of a plane.

18. What portion of the skew chisel does the cutting?

19. What is meant by shrinkage in pattern making?

20. How are the exact proportions of shrinkage obtained for different parts of the pattern?

21*a*. What is the usual proportion of draft to each twelve inches of surface on the face of a pattern for a cast-iron pulley?

21*b*. What proportions on the inside of the rim and on the hub?

22. When is it necessary to use mahogany, cherry or maple for patterns?

23. What is lead in a plane-iron, and what determines the amount?

24. Explain the use of a flask in moulding, and describe the two principal parts.

25. What allowance must be made on the pattern for shrinkage when the casting is to be made of iron?

26. Explain what is meant by *draft* in pattern making.

27. How should lumber for patterns be seasoned?

28. When a large piece is to be used for turning, should it be cut from a plank of the required thickness or glued up out of thinner stock? Give reasons for answer.

29. Explain the methods of grinding the brad-awl and the advantages of each method.

30. Explain the use of core prints.

31. What is the allowance for shrinkage of brass?

32. What are the usual allowances for draft?

33. What is meant by *finish* in pattern making?

34. When gluing up pattern stock, how is the pressure necessary to bring the glued surfaces in close contact usually obtained?

REVIEW QUESTIONS

ON THE SUBJECT OF

PATTERN MAKING.

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1. What are rapping plates?

2. Describe the process of gluing two thin pieces having large surfaces.

3. How is end wood treated if it is to be glued to other wood?

4. Explain why the upper core print sometimes has excessive draft, while the lower has but little draft.

5. What are fillets, and where are they used on patterns?

6. Give the dimensions for the arms of a six-arm pulley 40 inches in diameter and 12-inch face: (a) Width and thickness at hub. (b) Width and thickness at rim.

7. The pulley mentioned in Question 6 is to be fitted to a shaft $2\frac{9}{16}$ inches in diameter. (a) What should be the diameter of the hub? (b) What should be the length of hub?

8. What is a follow board, and when is its use necessary?

9. A pair of tight and loose pulleys 12 inches in diameter and $6\frac{1}{4}$ inches width of face, are to be fitted to a $1\frac{11}{16}$ inch snaft. (a) Give diameter of the hub. (b) Give length of hub.

10. What must be the outside diameter of the original wooden pattern for the rim of a pulley with six arms, the diameter of the finished pulley to be 30 inches and the width of face 9 inches?

11. (a) In the above pulley what should be the width and thickness of the arms at the rim? (b) What should be the width and thickness of the arms at the hub?

12. What are *core prints* and when do they form a necessary part of a pattern?

13. How are the two parts of a parted pattern held together for turning? Give two methods.

14. What are the proportions of alcohol and shellac gum for pattern maker's shellac varnish?

15. Is it always necessary to make a pattern in two parts?

16. How is colored shellac varnish made? (a) How is black made? (b) How red?

17. Give a sketch, including all dimensions, of the pattern for a plain brass cylinder which is to be finished "all over," the finished sizes being 6 inches long, 4 inches outside diameter, and 3½ inches inside diameter. All shrinkage rule measurements, allow $\frac{3}{32}$ inch for finish.

18. What is a core box, and for what purpose is it used?

19. What is used to give a hard, smooth surface to a completed pattern?

20. What color should be used for the inside of a core box?

21. How can the pattern for a small hollow cylinder be moulded if made in one piece, (not parted)?

22. Why are core prints shellaced in a different color from the body of the pattern?

23. What are *dowel pins*, and why are they used in a parted pattern?

24. How long a time should each coat of shellac have for drying before another coat is applied?

25. Give sketch showing shape and dimensions of core box for pattern mentioned in Question 17.

26. It is required to make the pattern for a five-arm 15-inch hand-wheel, the rim and hub of which are to be turned and finished. The finished diameter of the round rim is to be 1⅝ inches, and of hub 2¼ inches. Allowing $\frac{1}{16}$ inch for finish, give all dimensions for the wooden pattern, including width and thickness of arms at the rim and at the hub.

27. Give a sketch and all dimensions (shrinkage rule measurements) of the pattern for a cast-iron cylinder having a projecting flange, on each end (see Fig. 149), the cylinder to be bored out and finished all over, the finished sizes being as follows: Length 8 inches, diameter of flanges 5½ inches, thickness of flanges ⅜ inch, the diameter of the body of the cylinder outside 4 inches, and inside 3¼ inches, allowing ⅛ inch for finish.

28. Can the above pattern be moulded without being parted?

29. What is necessary after a coat of shellac is dry before applying another?

30. The pattern referred to in Question 17 could be made to form its own core. Give sketch including all dimensions for such a pattern.

31. Taking the moulder's time into consideration which is the better form for this pattern, solid or parted? Why?

32. Name the objections, if any, to casting the above cylinder in this way.

33. Give sketch and dimensions of core box for the cast-iron cylinder mentioned in Question 27.

REVIEW QUESTIONS

ON THE SUBJECT OF

FOUNDRY WORK.

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1. What is the meaning of the term "wrought iron"?

2. What is a flux? When is it used?

3. What is the difference between the cope and drag?

4. What is the weight of a cast-iron plate 16 inches square and 2 inches thick with a hole 3 inches in diameter through the center? Ans. 129.79 pounds.

5. What is loam?

6. How are cores dried?

7. How is blacking applied to a mold?

8. Why should a freshly daubed ladle be dried before using?

9. What grade of pig iron contains the largest proportion of combined carbon relatively to the whole amount in the iron?

10. What is the ordinary method by which castings are hardened?

11. What are chaplets?

12. What are risers?

13. How are the arms of large gears usually moulded?

14. Why are large gears and wheels usually cast in sections?

15. To what depth does the chill in castings extend?

16. Under what circumstances are loam moulds ordinarily used?

17. What should be the diameter of the shell of a cupola 24 inches in diameter?

18. What is the bed of a charge?

19. What is the best material from which to make flasks?

20. What is the upward pressure on a cope where there are three surfaces of 16, 35 and 48 square inches submerged respectively to the depths of 15 inches, 10 inches and 18 inches?

Ans. 379 pounds approx.

21. What is the most common form of dry sand moulding?

22. What is a cope?

23. What effect does the point at which the metal enters the mould have upon the pressures exerted, by the molten metal?

24. What is the difference in appearance between graphitic and combined carbon in pig iron?

25. What effect does manganese have upon the quality of iron?

26. What is the object of using a follow board?

27. What kind of cores are used for columns?

28. How is the full width of face for a pulley obtained?

29. What is the object of using a contracting chill?

30. How are loam moulds built?

31. What should be the height of a cupola that is 44 inches in diameter?

32. What is the pressure upon the bottom of a mould 24 inches below the surface of the gate, the area being 5 feet square?

Ans. 22,524.48 pounds.

33. What is the condition of the first iron that flows from the spout after putting on the blast?

34. What effect does chilling have upon the metal of a casting?

35. How should a mould with small cores and passages be poured?

36. What effect does silicon have upon the quality of iron?

37. What are the ordinary methods that are employed for cleaning castings?

38. What is the object of feeding a mould?

39. At what point is the metal usually poured into a pulley mould?

40. What is the chief characteristic of a good chilling iron?

41. In what way are loam moulds dried, other than in a core oven?

42. What is the first work to be done in the preparation of the cupola for melting?

43. What thickness of sand should be left about the cavities of a mould?

44. What is the weight of a cast iron ball 12 inches in diameter? Ans, 235.87 pounds.

45. How many grades of foundry irons are there?

46. What effect does phosphorus have upon the quality of iron?

47. What portion of a three-part flask is called the "cheek"?

48. How is the pattern for the spokes of a pulley placed in the mould?

49. How many coats of loam are usually applied in making a loam core?

50. What should be the diameter of the shell of a cupola which is 44 inches in diameter inside the lining?

51. How are the two parts of a flask made to register accurately when brought together after the pattern has been removed?

52. Of what are cores made?

53. What is the object of using blacking?

54. What effect does sulphur have upon the quality of iron?

55. What classes of castings can be made in open sand?

56. How are pipes usually cast? Why?

57. What is skinning loam?

58. What is the weight of a cast iron plate 1¾ inches thick and in the form of a trapezoid of the following dimensions; parallel sides 18 inches and 12 inches long respectively; perpendicular distance between parallel sides 9 inches? Ans. 61.59 pounds.

59. With what class of pig iron can the largest quantity of scrap be used?

60. How are large gears usually moulded?

61. What is the object of annealing chilled castings?

62. What should be the total area of the tuyeres in a cupola: (*a*) 32 inches in diameter; (*b*) 43 inches in diameter; (*c*) 66 inches in diameter?

63. What is the weight of a cast iron plate 1¼ inches thick in the form of an equilateral triangle, each of whose sides measures 16 inches? Ans. 43.35 pounds.

64. How should a large mould of heavy section be poured?

65. What means should be taken to avoid weakening castings where changes of direction occur in the surfaces?

66. How is a pulley to be moulded whose face is to be less than that of the pattern from which it is made?

67. What are some of the more common of the impurities contained in pig iron?

68. What is the upward pressure on a cope where there are two surfaces of 90 square inches and 1 square foot, submerged 18 and 21 inches respectively below the surface of the metal? Ans. 1210.69 pounds.

69. How are the parts of a flask held in position when the metal is being poured?

70. When is a three-part flask used?

71. When is a loam mould in the best condition for blacking?

72. How is sand prepared for moulding?

73. What is the principal foreign element in pig iron?

74. How are gears moulded where a full pattern is provided?

75. What properties should sharp sand possess?

76. What should be the height of a cupola that is 56 inches in diameter?

77. What is the object of blacking a core?

78. What is the upward pressure on a cope where the exposed surface is 2 square feet and the depth 19 inches? Ans. 1426.55 pounds.

79. What is the smallest number of teeth that should be placed in a sectional gear pattern?

80. What should be the principal ingredients composing moulding sand?

81. What precautions must be taken in cooling castings?

82. What kind of moulding is most practiced?

83. Why is hay rope used on loam cores?

84. What grade of iron contains the largest proportion of graphitic carbon?

REVIEW QUESTIONS

ON THE SUBJECT OF

FORGING.

1. Why is a piece of metal nicked in order to break it when cold?

2. What is the weight of a bar of flat iron $\frac{1}{2}$ inch thick, 2 inches wide and 13 feet 6 inches long?

3. What length of 3-inch round iron must be cut off to make a truncated cone having a bottom diameter of 3 inches, a top diameter of 2 inches and a height of 8 inches?

4. What is the welding color for laying steel upon iron?

5. What is the difference between drop forging and pressing?

6. What is the best form of weld for heavy shafts?

7. What effect does hammering have upon iron and steel when properly done?

8. How is the blast created for a forge?

9. What is the use of a swage and flatter?

10. What is the scale, and how is it formed?

11. Describe the process of brazing.

12. How are the heavy pieces usually handled under the hammer?

13. What is meant by the critical temperature of steel?

14. What air pressures are used for the blast?

15. Tell what you can of casehardening.

16. How should metal be piled on a shingle for fagotting?

17. What is the weight of a wrought-iron plate $\frac{5}{8}$ inch thick, 24 inches long and 10 inches wide?

18. What will be the length of a bar of iron at a temperature of 1050° F. if it is 6 feet 3 inches long at 60°?

19. What is the controlling factor in fixing the temperature to which steel can be heated without injury?

20. What is the best fuel to be used in a reverberatory furnace?

21. How does steel differ from cast and wrought iron?

22. Does water in itself tend to promote combustion in a forge fire?

23. What will be the length of a spike made from a bar 2 inches in diameter and 6 inches long? The spike to be in the form of a cone 2 inches in diameter at the base.

24. Describe drop forging.

25. Below what temperature should the hammering not be carried when making a forging?

26. How does a cold-shut injure a piece of metal?

27. Which can be heated to the higher temperature without injury, iron or steel?

28. What is the difference in the effect between plunging red hot steel into oil and water?

29. How should the scale be removed from a forging during the several stages of its completion?

30. What is the weight of a bar of round iron $1\frac{3}{4}$ inches in diameter and 9 feet 10 inches long?

31. What will be the final length of a bar of iron 4 inches in diameter and 2 feet long, that has been drawn down to a diameter of 2 inches for a finished length of 2 feet? The bar will thus be 4 inches in diameter with one end 2 inches in diameter for a length of 2 feet.

32. What precaution should be taken when locating the welds of heavy shafts?

33. What effect does increase of the carbon in steel have upon the welding of the metal?

34. What are the fluxes used with iron and steel?

35. How does a reverberatory furnace differ from the ordinary forge?

36. What materials are used for casehardening?

37. What portion of a marine engine shaft is subjected to the heaviest stresses?

38. What are the principal tools used for heavy forging?

39. What is the weight of a wrought iron shaft 12 inches in diameter and 10 feet long having a hole 5 inches in diameter along its axis?

40. What should be the properties of a good blacksmith coal?

41. What is the common temperature at which iron and steel are worked?

42. What is the object of using a flux in welding?

43. How should the hammering of a long shaft be done? That is, how should the blows be distributed?

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